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EFFECTS OF THE 1978 KATANGESE REBELLION ON THE WORLD COBALT MARKET

Congress of the United States
Office of Technology Assessment

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Charles River Associates Incorporated

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EFFECTS OF THE 1978 KATANGESE REBELLION ON THE WORLD COBALT MARKET

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TABLE OF CONTENTS

	Page
Chapter 1. SUMMARY	1-1
Chapter 2. COBALT MARKET, 1972-1976	2-1
Introduction	2-1
Cobalt Market Structure and Prices	2-2
Supply	2-4
Data Sources	2-4
Cobalt Mines	2-9
Copper Mines	2-9
Nickel Mines	2-14
Other Capacity	2-17
Cobalt Demand	2-17
U.S. Demand	2-17
Foreign Consumption	2-24
Dependence on Economic Activity	2-27
Other Issues	2-27
Recycling and Waste Disposal	2-27
Private Stocks	2-28
Government Policies	2-28
Chapter 3. IMMEDIATE IMPACTS OF THE COBALT SHORTAGE, 1978-1979	3-1
Cobalt in 1977	3-1
Summary of 1978-1979	3-1
Market Structure	3-3
Supply Response	3-3
Zaire	3-3
Zambia	3-4
Finland	3-5
Canada	3-5
Pacific	3-6
France	3-7
South Africa	3-8
United States	3-8
Other	3-9

TABLE OF CONTENTS (Continued)

Page

Chapter 3. IMMEDIATE IMPACTS OF THE COBALT SHORTAGE, 1978-1979 (Continued)

Demand Response 3-10
Superalloys 3-10
Magnets. 3-11
Hardfacing Materials 3-12
Cutting and Wear-Resistant Materials 3-13
Tool Steels. 3-13
Catalysts. 3-14
Other Chemicals. 3-14

Recycling 3-14
Superalloys. 3-14
Catalysts 3-15
Cutting and Wear-Resistant Materials 3-16
Other. 3-16

Private Stocks and Government Activity. 3-16

Summary 3-17

Chapter 4. COBALT IN THE 1980s. 4-1

Supply. 4-2
Zaire. 4-2
Zambia 4-3
Finland. 4-3
Canada 4-3
Pacific. 4-4
France 4-4
South Africa 4-5
United States. 4-5
Other. 4-6

Demand. 4-7
Superalloys. 4-7
Magnets. 4-7
Cutting and Wear-Resistant Materials 4-8
Welding and Hardfacing Materials 4-8
Tool Steels. 4-8
Catalysts. 4-8
Dependence on Economic Activity. 4-9

TABLE OF CONTENTS (Continued)

	Page
Chapter 4. COBALT IN THE 1980s (Continued)	
Other Issues	4-9
Recycling	4-9
Private Stocks	4-10
Government Activities	4-10
Summary	4-11

1

SUMMARY

Cobalt has a variety of applications, the most important being superalloys (principally used in jet engines), permanent magnets, and chemicals. Production is concentrated in a small number of countries, most notably Zaire, and is generally a byproduct of other mining and refining operations. Total U.S. consumption has ranged from 20 million pounds in 1978 to 12 million pounds in 1981, but U.S. mine production is zero. Noncommunist production of cobalt is in the range of 20,000 to 25,000 metric tons annually, about 10 percent of which is exported to the communist world.

The cobalt market was strong in 1973 and 1974, with U.S. demand peaking in those years, and with noncommunist world production also reaching new highs. Demand collapsed with the world recession that began in late 1974. The major producer, Gecamines in Zaire, curtailed production in 1976 and 1977, partly because it was experiencing technical and financial problems and partly because it did not want to build up stocks. Political events from 1975 to 1977, including the closing of Zaire's major rail link from the Copper Belt to the sea and a brief but ineffective invasion of Zaire, had no impacts on the cobalt market. Cobalt releases from the U.S. government stockpile, which had been expected to continue at significant levels for several more years, ended abruptly in 1976 when the cobalt objective was changed from about 11 million pounds to about 85 million.

The situation began to change in 1978, when demand began to increase very rapidly in response to a relatively strong world economy and a boom in the aerospace industry. As a result, a dealer market for cobalt developed, and the dealer price (as opposed to the producer price, at which Zairean and some other cobalt is sold) began to creep upward. Output from small producers and

excess stocks from consumers are traded in the dealer market. At the end of April 1978, sales agents for Zaire announced the institution of an allocation program for cobalt, because they did not have enough to satisfy the surging demand.

Shortly thereafter the market exploded. An invasion of Shaba Province in Zaire and the brief occupation of mining and processing centers by insurgents raised consumers' concerns over the continued availability of cobalt. Although the production facilities in Zaire had suffered minimal damage, these concerns and the growing demand for cobalt kept prices spiraling upward. The free market price peaked at over $40 per pound in late 1978, after which it began to decline gradually. The producer price was raised, in a series of steps, to $25 per pound in February 1979 -- four times its level 12 months earlier.*

The market began to respond to these price increases, although slowly at first. Cobalt is generally recovered as a byproduct of nickel or copper operations, so most producers had limited options in the short run. Several new cobalt refineries were rushed into full production; construction, and in some cases minor production, had been started before 1978. Other producers modified their operations to mine ores with higher cobalt contents, to improve cobalt recoveries in concentrating and refining, and to eliminate bottlenecks in processing. Construction began on new refineries as well.

Capacity in Zambia increased from 1,800 metric tons before the shortage to 3,600 metric tons by the end of 1979, although this increase was not caused by the shortage. Further capacity increases in Zambia were planned, amounting to an additional 3,200 metric tons. These may have been motivated at least in part by the cobalt shortage. Cobalt recoveries in Zambia certainly responded to the high cobalt prices in 1978 and 1979. Overall recoveries of cobalt in Zambia had been in the range of 30 percent in 1978 and 1979, but by 1980 they had risen to about 40 percent.

The Canadian nickel companies responded in various ways to the cobalt shortage. Sherritt Gordon increased the annual cobalt capacity of its refinery from 500 metric tons to 600 metric tons by the end of 1979, and to 1,000 metric tons by the end of 1981. Falconbridge increased the cobalt capacity of its nickel refinery in Norway from about 1,000 metric tons annually to 1,800 metric tons by the end of 1979, although it only has enough refinery feed to produce about 1,300 metric tons at current nickel production levels. Inco announced vague but ambitious plans to double its cobalt production, from about 700-800 metric tons annually to about 1,500-1,600. It did not do so immediately, however, and its efforts to keep production at its

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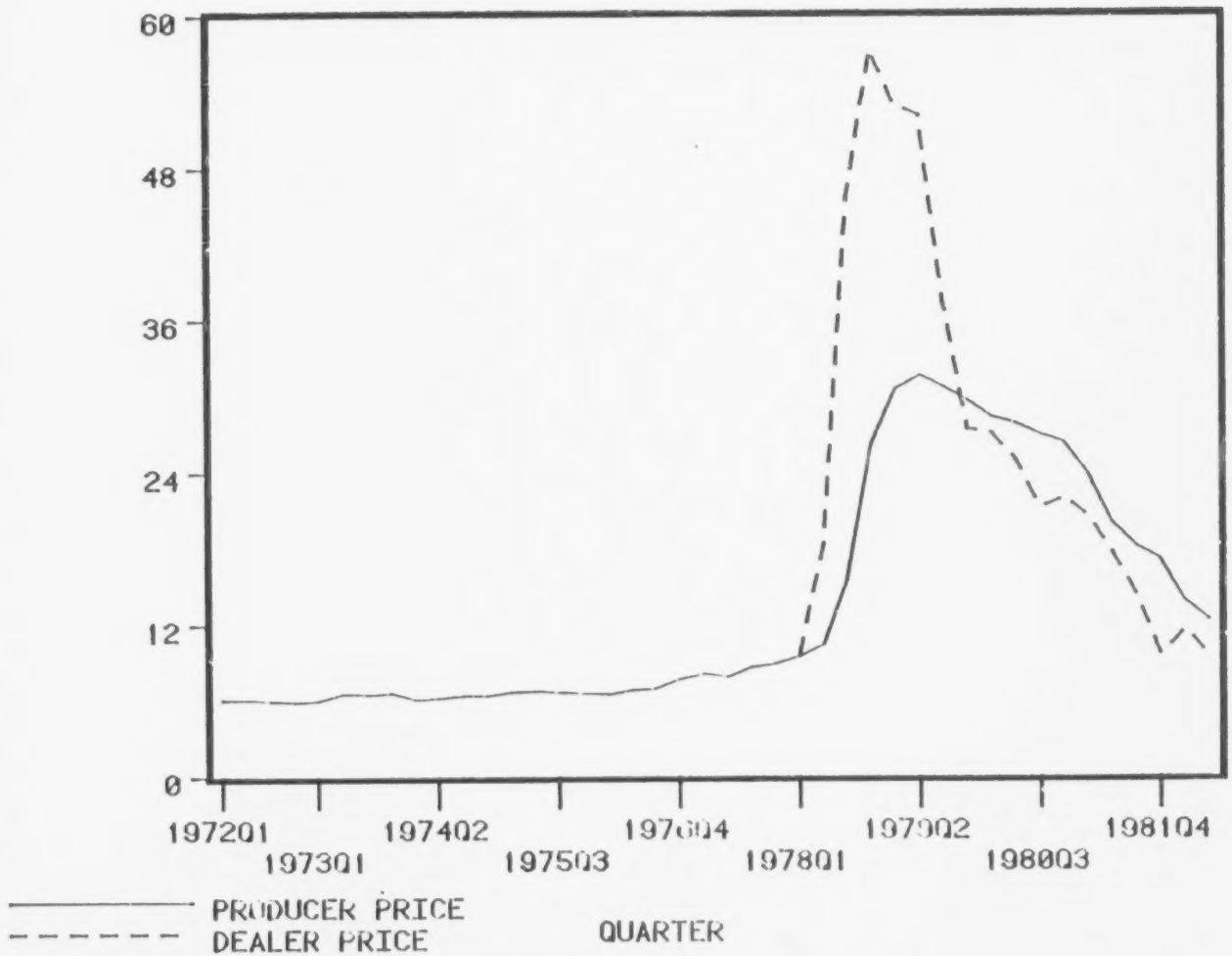
*Figure 1-1 shows the path of real prices in constant 1981 dollars from 1972 through mid-1982. Prices in the text are in nominal (i.e., current) dollars.

FIGURE 1-1: PRODUCER AND DEALER COBALT PRICES
(CONSTANT 1981 DOLLARS PER POUND)



former level were hampered by a nine month strike at its major nickel operations in Canada in 1978-1979. In 1980 Inco announced plans for a 900 metric ton per year electrolytic cobalt refinery, to be completed by the end of 1982. Some of the feed for this plant would be material already being refined by Inco, Sherritt Gordon, or Falconbridge.

Production in the Pacific region increased fairly substantially from 1978 to 1981, partly due to the cobalt shortage but mostly for other reasons. Greenvale (Australia) and Marinduque (Philippines) were nickel laterite projects that came into production in the mid-1970s, sending cobalt intermediates to Japan for refining. The mines and refineries increased production toward capacity in the several years after their opening, so their output rose steadily during the cobalt shortage. They did, however, take steps to increase cobalt production above the levels it would otherwise have reached. Greenvale selectively mined cobalt-rich parts of its orebody, and Marinduque increased the cobalt content of its intermediates.

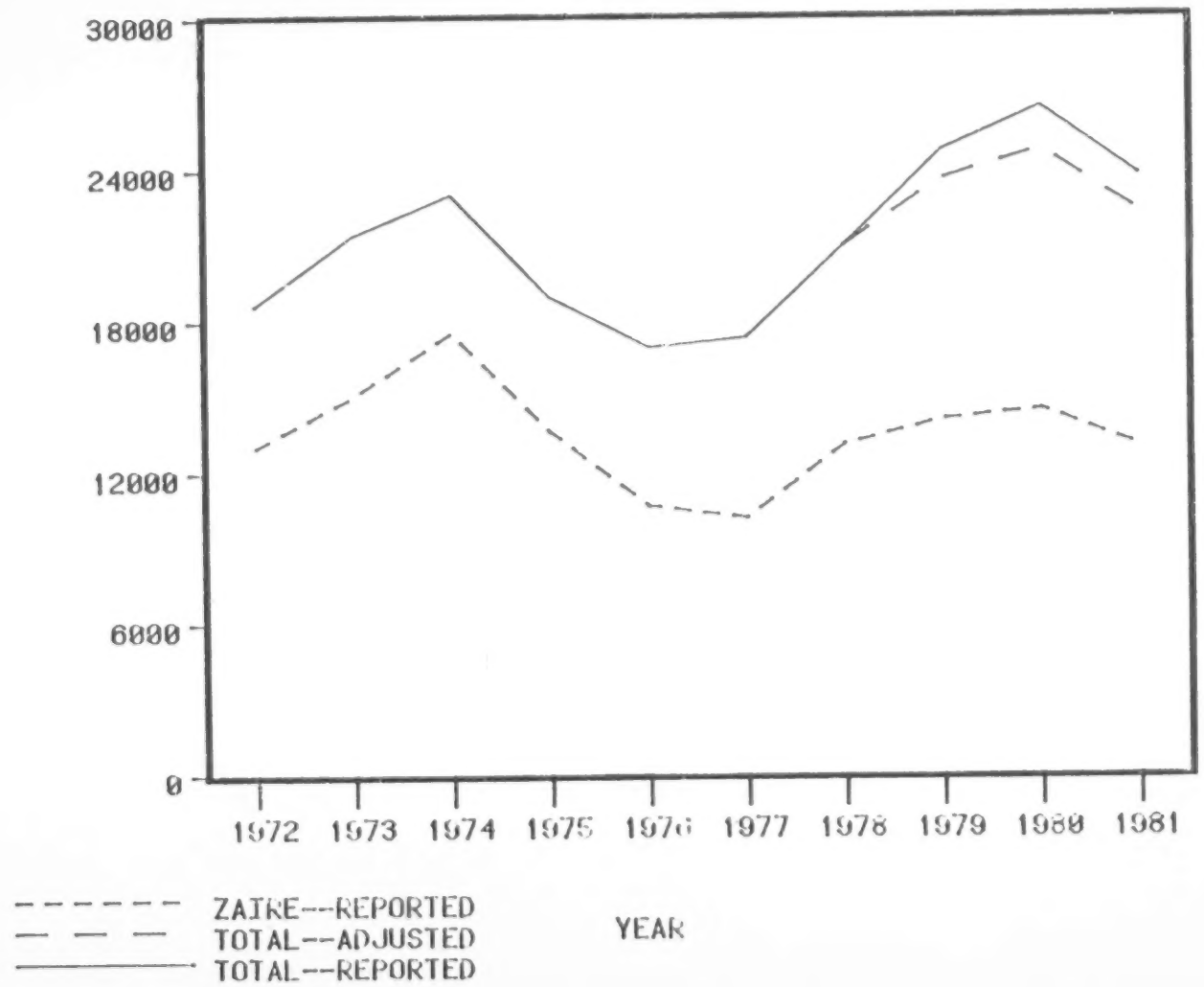
Finland increased its cobalt capacity from about 1,000 metric tons before the shortage to about 1,450 metric tons by the end of 1979, but this increase had been planned earlier. The platinum companies in South Africa installed cobalt recovery circuits in their nickel refineries, adding about 500 metric tons to world capacity between 1979 and 1982. This was definitely in response to the cobalt shortage. Interest in cobalt production rose in other parts of the world, but not to the extent of increasing capacity.

Increases of less than 3,000 metric tons of capacity can be directly attributed to the cobalt shortage (about 10 percent of noncommunist capacity), although the new, 2,600 metric ton refinery in Zambia might be attributed in part to the shortage. Capacity utilization certainly increased during the shortage, but high levels of capacity utilization will not be maintained in periods of lower prices.

The estimated impacts of the high cobalt prices on noncommunist production in the 1978-1981 period are summarized in Figure 1-2. This graph compares reported production with estimates of what production would have been if prices had remained at their pre-1978 levels. It assumes that production in Zaire was not affected by the cobalt shortage. It also does not show the effects of new capacity coming into production in 1982.

The effects of the high prices on cobalt demand were not felt immediately, but gradually and into 1980 and 1981. U.S. cobalt demand in superalloys eventually fell by about 10 percent as a result of the high prices, and demand in magnets fell about 40 percent due to price effects. Most of these declines were probably permanent. Cobalt consumption in cutting and wear-resistant materials (cemented carbides) and in catalysts was not

FIGURE 1-2: ESTIMATED PRICE EFFECTS ON NONCOMMUNIST WORLD COBALT SUPPLY
(METRIC TONS)



immediately affected by the cobalt shortage. Eventually, however, consumption in catalysts is likely to fall permanently by 10 to 25 percent. Cobalt consumption in other uses probably fell by 10 to 30 percent as a result of the high prices, but these declines are reversible with lower cobalt prices. Probably only one-third to one-half of these price effects were operative by the end of 1979. Much of the fall in reported consumption in the United States can be attributed to a weak economy, high interest rates, and changes in data reporting practices. Reported cobalt consumption in the United States was 11.7 million pounds in 1981; if the cobalt shortage had never occurred, it would probably have been about 13 to 15 million pounds. Similar demand effects occurred in other countries, although the ovrall impacts differed due to the different mix of uses for cobalt outside the United States.

Recycling became very important during the cobalt shortage, probably saving 10 to 25 percent of domestic consumption in superalloys and lesser amounts in other metallic uses. Much of this recycling involved new scrap that might not be included in the available data. Plants for recycling spent hydrodesulfurization catalysts are still being constructed. If they prove successful, demand in catalysts could fall by 35 to 45 percent.

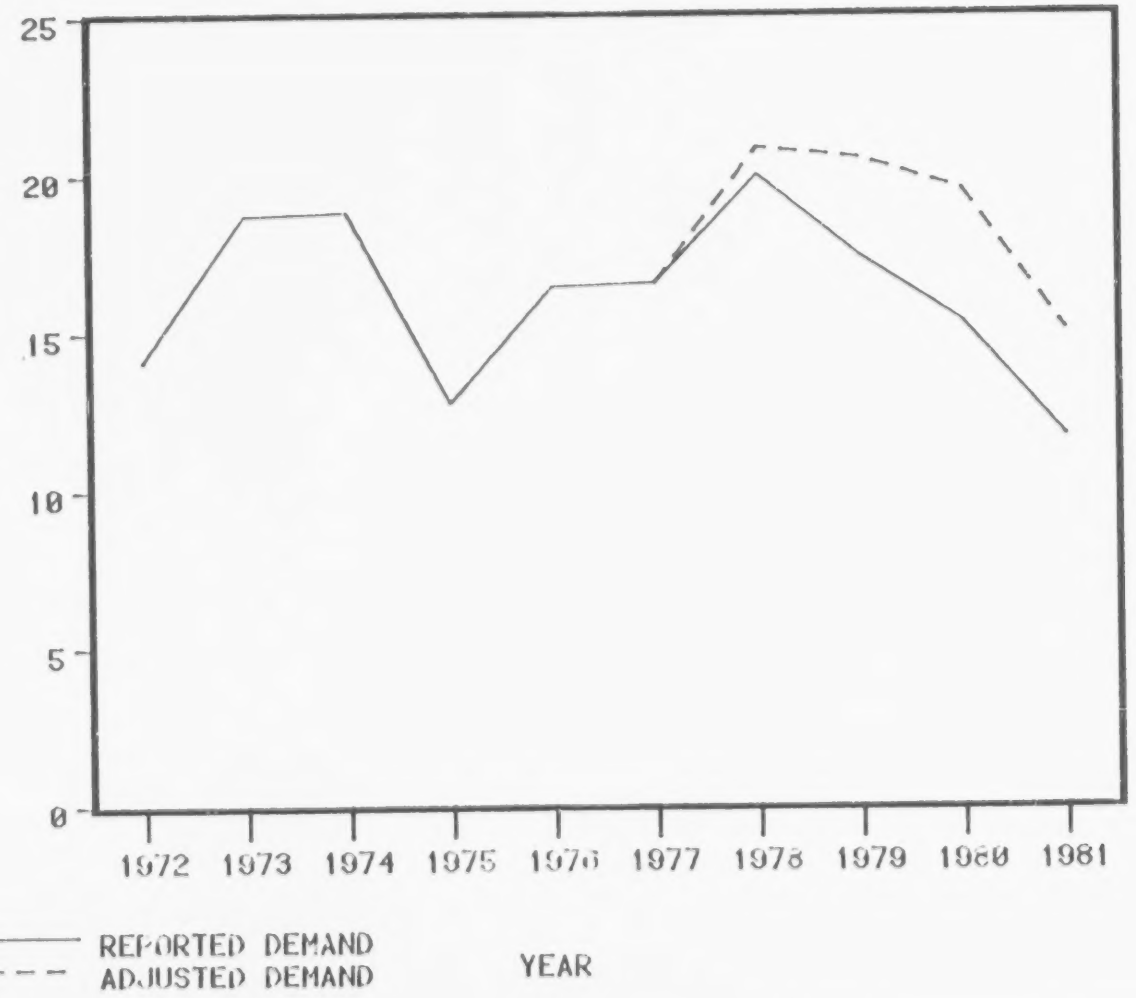
The combined impacts of substitution, conservation, and recycling on U.S. demand over the 1978-1981 period are summarized in Figure 1-3. This graph compares reported consumption with estimates of what consumption would have been if prices had remained at their pre-1978 levels in real terms.

In late 1979 and early 1980 the overall demand for cobalt began to fall, partly due to the weak economies in the United States, Europe, and Japan, and partly due to substitution and conservation measures. U.S. cobalt consumption in 1981 was at its lowest level in over five years, and consumption in 1982 will be even lower.

As a result, the cobalt bubble burst in 1981. In that year the producer price was lowered in several steps from $25.00 per pound to $17.26 per pound, with few sales being made even at that price. The dealer price plummeted from about $21.00 per pound at the beginning of the year to under $10.00 by December, after which it rebounded slightly. In February 1982, the producer price was cut again, to $12.50 per pound. The dealer price drifted down to under $10.00 per pound. As of the fourth quarter of 1982, the sales agents for cobalt from Zaire are discounting from their published price, and dealer prices are below $5.00 per pound.

Supply is likely to exceed demand for several years, which will maintain the downward pressure on prices. The demand for cobalt in superalloys will remain slack until the aerospace market recovers, which is likely to be two or more years away, but could prove to be strong. Cobalt consumption in

FIGURE 1-3: ESTIMATED PRICE EFFECTS ON U.S. COBALT DEMAND
(MILLIONS OF POUNDS)



magnets has a potentially bright future in as-yet undeveloped uses. The demand for cobalt in cemented carbides will depend to some extent on the strength of the oil market -- high oil prices mean substantial drilling activity and strong demand for drill bits. In all other uses, cobalt demand is likely to grow at about the same rate as industrial production. The recycling programs that were instituted so successfully during the shortage may not be able to survive these low prices.

Chapter 2 of this report discusses the cobalt market in the mid-1970s, the period just prior to the cobalt shortage. The events of 1978-1979 are recounted in Chapter 3. A discussion of the cobalt market from 1980 to the present, and an assessment of the future, are contained in Chapter 4.

2

COBALT MARKET, 1972-1976

INTRODUCTION

Production is concentrated in a small number of countries, most notably Zaire. Because of this concentration, the cobalt market has not been overly competitive in the past. The major producer generally held the price fairly steady in real terms, adjusting it occasionally in line with market conditions in order to maximize long-run profits or revenues. Cobalt is generally recovered as a byproduct of other mining and refining operations, so at historical price levels the potential for increasing cobalt output around the world from other sources was quite limited. Cobalt is used in a variety of important applications, the most important being superalloys, permanent magnets, and chemicals. Consumption by use differs considerably across countries.

This chapter will begin with a discussion of the historical structure of the cobalt market and cobalt prices, and continue with sections on supply, demand, and other important market factors. The chapter will concentrate on the market in the period from 1972-1976, just prior to the first of the two invasions of Zaire's Shaba Province, where the cobalt operations are located. Data will be presented for the period from 1972 to the present, whenever possible. It should be noted that historical data for the cobalt market are difficult to obtain, unreliable, or both. Where appropriate we will indicate some of the problems with the available data, for both the 1972-1976 period and later years.

COBALT MARKET STRUCTURE AND PRICES

As mentioned above, the cobalt market is highly concentrated. In a typical year, Zaire (formerly the Belgian Congo) accounts for 60 percent or more of noncommunist world cobalt production. Prior to Zaire's independence and eventual nationalization of its mining operations, Union Miniere in Belgium had controlled the production and subsequent marketing of copper and cobalt from the region's rich orebodies. Econometric evidence indicates that Union Miniere acted in the manner of a dominant producer attempting to maximize long-run profits, taking into consideration the state of the world economy, the response of demand to price changes, the availability of production from other sources, and the stockpiling activities of the U.S. government.

After the copper/cobalt operations in Zaire were nationalized, the Belgians continued to be involved in the marketing of cobalt. The national minerals sales corporation, Sozacom, was not formed until the early 1970s. It still does not market most of its products directly to consumers, but through the sales organizations set up in the past by the Belgians. As a result, the nationalization of the mining operations in Zaire and the later move to market the output from these operations had little impact on the cobalt market.

The history of cobalt prices for several major cobalt products is summarized in Table 2-1. Producer prices are for material produced in Zaire and sold through the producer's agents. Since early 1978 a vigorous dealer market for cobalt has developed, and many of the producers other than Zaire have sold their material at or near these merchant prices.* From 1940 through 1972 the cobalt price was relatively stable, rarely changing more than once a year. In 1973 and 1974, with the general commodity boom and the first major oil price escalation, prices changed several times. From 1975 through 1977 prices were relatively stable, considering the rates of world inflation in those years. Essentially no dealer market for cobalt existed prior to 1978, although some sales were made through dealers during the height of the nickel shortage in 1969.

The dates given in Table 2-1 are the effective dates for changes in the producer prices. The free market (dealer) prices are much more volatile than the producer prices and change from day to day, so no separate dates for their changes are given. Instead, Table 2-1 presents the beginning of month dealer price for cobalt for the time period closest to the effective date of the producer price change.

Cobalt is sold in a wide variety of products and forms, the most common being electrolytic cathode. High-purity cathodes have been the product most commonly used in the superalloy industry and other industries with stringent purity specifications. Cobalt is also commonly produced as a hydrogen-reduced powder, with the powder sometimes briquetted or sintered

*A dealer market can allocate supplies to consumers more efficiently than a producer market in the short run, in the sense that consumers for which cobalt has only a low or moderate value reduce or eliminate their purchases.

Table 2-1

U.S. COBALT PRICES, 1972-1982
(Dollars per Pound)

			Producer			
Year	Month	Day	Cathode	Extra-fine Powder	70 percent Oxide	Dealer
1971	December	27	2.45	3.89	2.27	-
1973	February	14	3.00	4.65	2.73	-
	August	13	3.30	5.11	3.00	-
		28	3.20	4.95	2.91	-
	November	28	3.10	4.80	2.82	-
1974	January	7	3.10	5.06	2.90	-
	April	26	3.30	5.38	3.09	-
	May	15	3.45	5.63	3.23	-
	July	8	3.75	6.61	3.63	-
1975	January	23	4.00	7.05	3.87	-
1976	April	15	4.40	7.45	4.16	-
	September	13	4.90	8.29	4.62	-
	December	24	5.40	9.14	5.09	-
1977	January	21	5.20	8.80	4.90	-
	July	13	6.00	9.89	5.57	-
	December	21	6.40	10.55	5.93	-
1978	February	24	6.85	11.29	6.35	7.00
	May	23	8.50	12.69	7.44	21.50
	July	25	12.50	17.42	10.53	34.50
	September	14	18.00	23.60	14.76	34.00
	October	27	20.00	26.22	16.40	47.50
1979	February	1	25.00	31.00	19.91	38.00
1980	March	28	25.00	32.25	19.91	22.25
1981	March	2	20.00	27.26	16.34	13.00
	August	3	17.66	-	-	14.95
	September	1	17.26	-	-	12.25
1982	February	1	12.50	18.13	9.77	11.88
	May	1	12.50	16.36	8.74	10.40

SOURCES: Producer prices from Metals Week, with effective dates of price changes.

Dealer prices from Metal Bulletin, midpoint of range for beginning of month closest to date of producer price change. For example, methane price at beginning of August given for producer price change on July 25 (1978) and August 3 (1981).

before shipping. Cobalt can be processed into a variety of chemicals for sale to the chemical industries, the most important chemical form being cobalt oxide (either 70 percent or 72 percent cobalt grades). Specialty products include extra-fine powder, used in producing cemented carbides. Prices of three major cobalt forms are presented in Table 2-1. The granule/cathode price refers to high-quality material suitable for use by all cobalt consuming industries. Extra-fine powder and ceramic-grade oxide have generally sold at a premium over the cathode price, in terms of contained cobalt.

SUPPLY

Zaire is the most important source of cobalt in the noncommunist world (Tables 2-2 and 2-3). The state mining company, Gecamines, recovers cobalt in the course of copper mining and processing operations in Zaire. Zambia is the second largest source of cobalt, also as a byproduct of copper operations. Morocco has the only cobalt deposits exploited primarily for their cobalt; refining of these ores is done in France. Intermediate cobalt products are recovered from nickel operations in Australia and the Philippines, then processed further in Canada, the United States, and Japan. Intermediate nickel products from New Caledonia and Botswana are processed in France and the United States for cobalt recovery. Cobalt in Canadian nickel ores is partially processed in Canada, with recovery completed in Canada, Wales, and Norway. Finland recovers cobalt from its own copper ores, as well as from East German copper residues. Platinum operations in South Africa produce significant quantities of nickel, from which cobalt has been separated in Canada, Norway, the United States, and South Africa. Cobalt is also produced from nickel operations in Zimbabwe.

Because cobalt is only found in complex ores, the costs of producing it depend on many factors. These include the grades of major metals and other byproducts in the ore, the specific type of mineralization, the scale of operation, the depth and thickness of the orebody, and the prices for the other metals in the ore. Given the nature of cobalt-bearing ores, the amount of cobalt reserves depends primarily on the amount of cobalt that can be recovered from nickel and copper reserves.

DATA SOURCES

The major source of data on cobalt production around the world is the United States Bureau of Mines, which publishes annual estimates of mine production and metal production of cobalt. Although this is the best overall source of information, and other sources generally just quote the Bureau of Mines data, it has some problems. The metal production data seem more reliable than the mine production data, because better information can usually be obtained on the final production of a byproduct than on its mine production. The metal production data are slightly mislabelled by the Bureau of Mines, because they

Table 2-2

MINE PRODUCTION OF COBALT IN THE NONCOMMUNIST WORLD
(Metric Tons)

	Australia	Botswana	Canada	Finland	Morocco	New Caledonia	Philippines	Zaire	Zambia	Zimbabwe	Total
1972	NA	--	1,520	1,270	1,602	NA	41	13,112	3,345	--	24,835
1973	NA	6	1,517	1,270	1,422	NA	41	15,052	4,300	--	29,418
1974	NA	33	1,564	1,270	1,627	NA	30	17,632	2,379	--	30,885
1975	NA	81	1,354	1,402	1,961	NA	117	13,638	1,843	--	20,396
1976	544	132	1,356	1,278	934	82	492	10,686	2,175	--	17,679
1977	1,000	163	1,485	1,227	1,015	109	1,084	10,215	1,704	--	18,002
1978	1,350	261	1,234	1,212	1,134	150	1,191	13,299	3,741	18	23,590
1979	1,500	294	1,640	1,065	961	210	1,370	14,996	4,280	210	26,526
1980	1,600	226	1,603	1,035	838	180	1,331	15,500	4,400	120	26,833
1981e	1,600	250	2,270	1,035	752	140	1,090	15,500	4,500	80	27,217

Notes: Data reported for Australia and New Caledonia in 1975 are inconsistent with data for later years, so are not presented here.
Data for South Africa are not available.

SOURCE: U.S. Bureau of Mines. Minerals Yearbook (Annual); and Mineral Industry Surveys. Washington, D.C.: U.S. Government Printing Office.

Table 2-3

PRODUCTION OF REFINED COBALT IN THE NONCOMMUNIST WORLD
(Metric Tons)

Year	Canada*	Finland**	France+	West Germany	Japan++	United States#	Zaire	Zambia	Total
1970	2,069	1,008	304	826	--	147	13,374	2,052	19,780
1971	1,961	925	576	601	--	140	14,518	2,080	20,801
1972	1,520	803	774	457	--	--	13,043	2,053	18,650
1973	1,517	1,010	835	370	11	--	15,052	2,664	21,459
1974	1,564	812	769	356	10	--	17,565	1,964	23,040
1975	1,490	820	769	340	48	30	13,638	1,843	18,978
1976	1,563	892	725	250	515	165	10,686	2,175	16,971
1977	1,890	985	852	400	1,093	221	10,215	1,704	17,360
1978	1,516	922	905	350	1,864	292	13,125	2,063	21,029
1979	1,977	1,162	921	385	2,653	421	14,100	3,176	24,795
1980	2,421	1,150	1,433	400	2,867	454	14,482	3,310	26,517
1981e	2,764	1,230	1,400	400	2,421	406	13,000	2,570	23,791

*Cobalt refined by Canadian nickel companies in Canada, Norway, and Wales. Includes material from Canada, Australia, South Africa, and other sources.

**Primarily material of Finnish origin. Processing of East German residues began in 1979.

Footnotes and Sources continued on following page.

Table 2-3 (Continued)

PRODUCTION OF REFINED COBALT IN THE NONCOMMUNIST WORLD
(Metric Tons)

+Primarily material from Morocco. In 1979, processing of small quantities from New Caledonia began.

++Material from Australia and the Philippines.

#Since 1975, includes material from Australia, Botswana, New Caledonia, and South Africa.

[e]Estimated.

SOURCES: U.S. Bureau of Mines. Minerals Yearbook (Annual). Washington, D.C.: U.S. Government Printing Office; contractor estimates; Company annual reports and 10-K reports. Copper Industry Service Bureau. Zambia Mining Yearbook (annual). Kitwe, Zambia.

usually include production of cobalt in any form that can be sold to a consumer, including cobalt oxide. A more serious problem is that data seem inaccurate for certain countries in certain years. For example, in recent years the metal production data for Canada do not agree with the figures published by Sherritt Gordon, the only current operator of a cobalt refinery in Canada. In other years countries like Botswana and Zimbabwe have had metal production reported, although these countries in fact produce only cobalt intermediates that are processed elsewhere.

The mine production data are exceedingly unreliable. One major question seems to have been resolved in different ways over the years: what is meant by mine production of cobalt? Should it reflect all of the cobalt in an ore that is mined, whether or not the cobalt is recovered, or should it include only that portion of the cobalt that is eventually recovered? In many cases no choice is available; a country will provide the Bureau of Mines only with information on the cobalt eventually recovered from the ore, so the data are published with mine production equal to metal production, or with footnotes indicating that mine production equals the recoverable cobalt contained in materials refined elsewhere. In other cases a choice must be made, and that choice is not always clear. In the past the Bureau of Mines reported the cobalt content of the nickel ores in New Caledonia and Australia as cobalt mine production in those countries. The problem, particularly for New Caledonia, is that not all of this cobalt is recoverable. Most of the nickel ores in New Caledonia are processed into ferronickel, from which the cobalt cannot be separated. Ferronickel is generally priced on the combined nickel plus cobalt content, implying that the cobalt in ferronickel is sold to steel producers as nickel, not as cobalt.* In general only about 10 percent of the cobalt in New Caledonia's nickel ores has been recoverable, given the processing facilities used. As a result, consistent time-series of mine production data are difficult to collect.

The mine production data presented in Table 2-2 are essentially those reported by the Bureau of Mines, except that the data for Australia and New Caledonia have been changed to not available through 1975, to avoid the lack of comparability with later data. The refined production data are essentially the metal production data of the Bureau of Mines, with some modifications. Other sources, such as company annual reports and 10-K reports, the Canadian Minerals Yearbook, and the Zambian Mining Yearbook, have been used as well. Communist production of cobalt has not been included in the tables, because East-West trade in cobalt is minor, and the communist world is a net importer of the metal.

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*This ferronickel cannot be used in producing stainless steel for nuclear applications, because of its cobalt content. For all other uses, however, stainless and alloy steels made from cobalt-rich ferronickel are perfectly acceptable.

COBALT MINES

At present only one company in the world operates a mine primarily for its cobalt, Compagnie de Tifnout Tiranimine in Morocco. The cobalt arsenide ores near Bou Azzer in Morocco average about 1.2 percent cobalt. The ores are concentrated in Morocco to 10.0 to 12.0 percent cobalt, then shipped to France for processing. Until 1975, production was typically about 2,000 metric tons of cobalt in concentrates annually, but production began to decline after that. Reserves were never a large multiple of production for this operation throughout its long history, because the mineralogy of the region is complex, and the cost of proving reserves well in advance of production was considerable. The company has periodically announced that its reserves were at a perilously low level, but in the past it has always managed to find more cobalt.

COPPER MINES

Three countries recover important quantities of cobalt from copper mines -- Zaire, Zambia, and Finland. Zaire is by far the most important in this group, and Finland the least.

ZAIRE

Zaire's ores are among the richest in the world, grading about 0.3 to 0.5 percent cobalt in the deposits that supply the cobalt plants. Ores with lower cobalt contents are not processed for cobalt recovery in Zaire, although they would be considered high grade anywhere else in the world. Most of Zaire's copper comes from open-pit mines, although two underground mines are important sources of copper and cobalt. All ores that will be treated for cobalt recovery -- sulfide, oxide, or mixed -- are milled to produce bulk concentrates, not separate copper and cobalt concentrates. The bulk concentrates are fed to one of two huge hydrometallurgical plants, which produce cobalt cathodes and low-quality copper cathodes. In order to produce copper, these plants must go through all but the final stages of cobalt recovery.

The two hydrometallurgical plants use similar processes, although they differ in some respects. Concentrates are leached in spent copper electrolyte and sulfuric acid. The leach solution is purified by altering the pH (by adding lime or acid) and filtering. Most of the copper is then electrowon in the copper tankhouse. Some of the spent copper electrolyte is bled to the cobalt tankhouse, where it undergoes another series of purification steps. The cobalt is then electrowon. In the old Shituru refinery, the cobalt cathodes are generally of fairly low quality, so they are melted to eliminate some impurities and granulated in water. The newer Luilu refinery produces high-quality cathodes. The Shituru refinery has a nominal capacity of 7,800 metric tons of cobalt annually, and the Luilu refinery a capacity of 9,000 metric tons (Table 2-4). Small quantities of cobalt are sometimes produced in the form of "white alloy," essentially a copper-cobalt matte; this material is refined in Belgium. These capacities have not changed appreciably since 1960.

Table 2-4

FINISHED COBALT CAPACITY, NONCOMMUNIST WORLD: DECEMBER 1982

Country	Company	Nominal Capacity (Metric Tons)	Principal Sources of Cobalt	Product
Canada	Inco	900	Canada - nickel matte	Electrolytic rounds
	Sherritt Gordon Mines	1,000	Canada - ore; Australia - mixed sulfides	Powder, briquettes
Finland	Outokumpu Oy	1,400	Finland - ore; GDR - residues	Powder, briquettes, salts
France	Metaux Speciaux	1,500	Morocco - cobalt concentrate	Electrolytic, oxides, salts
	SLN	600	New Caledonia - nickel matte	Chloride solution
Federal Republic of Germany	Duisburger Kupferhutte, Gesellschaft fur Elektro-metallurgie	500	Residues	Shot
Japan	Nippon Mining	1,320	Australia - mixed sulfides	Electrolytic cathode
	Sumitomo Metal Mining	1,680	Philippines - mixed sulfides	Electrolytic cathode
Norway	Falconbridge Nikkelverk	1,800	Canada - nickel matte	Electrolytic cathode
South Africa	Impala Platinum	200	Matte from platinum ores	Powder?
	Matthey Russenburg Refiners	500	Matte from platinum ores	Sulfate
United Kingdom	Inco	450	Canada - oxide; Indonesia - matte	Oxide and salts
United States	AMAX Nickel	450	Australia, Botswana - matte	Powder, sintered cube

(Continued on next page)

Table 2-4 (Continued)

FINISHED COBALT CAPACITY, NONCOMMUNIST WORLD: DECEMBER 1982

Country	Company		Nominal Capacity (Metric Tons)	Principal Sources of Cobalt	Product
Zaire	Gecamines	(a) Luilu	9,000	Copper - cobalt concentrates	Electrolytic cathode
		(b) Shituru	6,800	Copper - cobalt concentrates	Granules
Zambia	ZCCM	(a) Rokana I	1,800	Copper - cobalt concentrates	Electrolytic cathode
		(b) Rokana II	2,600	Copper - cobalt concentrates	Electrolytic cathode
		(c) Chambishi	2,400	Copper - cobalt concentrates	Electrolytic cathode

SOURCE: Contractor estimates.

Cobalt production in Zaire peaked in 1974, at 17,565 metric tons of finished cobalt. This includes cathodes and granules for final sale, as well as granules, low-quality cathodes, and white alloy to be processed further in Belgium. Metallurgie Hoboken-Overpelt, a Union Miniere affiliate, operates a cobalt plant at Olen that produces a variety of cobalt products, especially chemicals and extra-fine powder, primarily from cobalt of Zairean origin. As a result, the capacity of this plant is not generally included in total world capacity, because doing so would otherwise lead to double-counting of that portion of Zaire's output that is processed at Olen.

Cobalt production fell off sharply in 1975 and 1976. One reason was the poor financial state of Gecamines and Zaire in general, due to the collapse of the copper market in late 1974. With foreign exchange earnings sharply reduced, expenditures on repair, maintenance, and stripping (removing waste material to prepare for future mining) had to be curtailed. Another reason was the desire to cut back finished production to keep stocks of cobalt from accumulating. Instead, Gecamines stockpiled cobalt hydroxide in 1976 and 1977. This intermediate material must be produced if copper is to be produced in the hydrometallurgical plants. Only minor steps are required to process the stockpiled cobalt hydroxide into metal.

One major development took place in late 1975 that affected both Zaire and Zambia. The civil war in Angola that broke out after the Portuguese withdrew cut off the Benguela railway, which had been the major route between the Central African Copper Belt and the rest of the world.* Most of the copper and cobalt exported from Zaire and Zambia had been shipped via that route, as had most imports of machinery and supplies. When the railway was suddenly closed, both Zaire and Zambia had to scramble for alternative transportation routes. These eventually included the Tazara railway from Zambia to Tanzania (and Kenya, when Tanzania and Kenya are on good terms), the southern route through Zimbabwe (then Rhodesia) to South Africa, and Zaire's own lengthy, meandering route to its own port. Cobalt can be (and has been) flown from Zaire to Europe, but the transportation routes are essential for exports of copper and imports of equipment and supplies.

Two expansion programs were started in Zaire in the mid-1970s. The P2 project of Gecamines included two new open pit mines (Dikuluwe and Mashamba), an ore crusher and concentrator (DIMA), a coke pulverization plant, a flash smelter, and an electrorefinery, to increase copper capacity by about 100,000 metric tons and cobalt capacity by about 6,000 metric tons.** The Tenke-Fungurume project was being developed by a consortium of companies that did not include Gecamines, although its deposit is in the same region where Gecamines has its

*The Benguela railway is still closed in 1982, and is likely to remain closed until peace comes to Namibia and Angola. Sporadic attempts have been made to reopen it, but bridges are vulnerable to guerilla attack. The railroad will require substantial renovation before reopening.

**The mines were completed before the invasion of 1978, and the concentrator became operational in 1980. Work had been started on the other projects before the invasion, but they are likely to remain unfinished at least until the mid-1980s.

operations. The original plan called for a mine-refinery complex, with a cobalt capacity of about 6,500 metric tons annually. Progress halted in 1976, however, due to the high costs of the project, and it is unlikely to resume before the mid-1980s.

In connection with these expansion projects, Zaire is constructing a huge, high-voltage direct current power line to bring hydroelectric power 1,000 miles through the jungle from the Inga dam to the copper-cobalt operations in Shaba Province.

ZAMBIA

Zambia is the second most important source of cobalt in the noncommunist world. Two copper companies have produced cobalt in Zambia -- Nchanga Consolidated Copper Mines (NCCM) and Roan Consolidated Mines (RCM).*

Although the two cobalt operations in Zambia are different in many ways, they are similar in many others. Both companies have mines with cobalt contents ranging from 0.1 to 0.2 percent, together with copper contents of 1.5 to 3.0 percent. The ores are ground and floated to produce a copper concentrate, then again to produce cobalt concentrates. NCCM has for many years operated a cobalt plant (Rokana I) with a nominal capacity of 1,800 metric tons. In the 1972-1976 period this refinery generally operated above its nominal capacity, because it treated not only about 1,300 metric tons per year of its own concentrates, but also about 600 metric tons or so annually of cobalt in hydroxide from RCM. The limiting factor on capacity in the NCCM refinery was the copper-cobalt ratio in the cobalt concentrates. The cobalt hydroxide from RCM provided additional cobalt but no copper, so it could be treated without difficulty.

The mining companies in Zambia were nationalized in the early 1970s, but this had no immediate impact on their operation, organization, or marketing. Most of the cobalt produced in Zambia in the early- to mid-1970s was sold in Europe, particularly the United Kingdom. All of the cobalt shipped from Zambia has been electrolytic cathode, directly usable by consumers.

FINLAND

In the mid-1960s the Finnish state mining company, Outokumpu Oy, operated a cobalt refinery with a capacity of about 1,000 metric tons annually. Very low-grade cobalt concentrates are produced and processed as a byproduct of

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*These companies merged, effective March 31, 1982, to form Zambia Consolidated Copper Mines. They will be referred to by their old names in this report, to minimize confusion.

copper mining operations in Finland, providing about 800 metric tons of cobalt annually. Small quantities of cobalt intermediates from Outokumpu's nickel refinery are also used as refinery feed. Until the mid-1960s, this material had all been shipped to West Germany for refining. The major product of this refinery has been powder.

NICKEL MINES

Essentially all the rest of the noncommunist world's cobalt is a byproduct of nickel mining and processing operations. Cobalt is recovered from both nickel sulfides and nickel laterites,* by means of either hydrometallurgical or pyrometallurgical processes. Most of the world's cobalt resources found in nickel ores are in nickel laterites, but at present most of the cobalt recovered as a byproduct of nickel operations comes from sulfides, which also provide most of the world's nickel. Nickel laterites generally range from about 1.5 to 3.0 percent nickel, with a typical cobalt content of about 0.15 percent. The nickel to cobalt ratio is therefore typically in the range of 10 or 20. Nickel sulfides generally range from about 0.5 to 3.0 percent nickel, but they have much lower cobalt contents. A typical nickel to cobalt ratio for sulfides is about 50.

CANADA

Cobalt supply flows involving Canada are fairly complex. Inco and Falconbridge Nickel Mines recover cobalt from the nickel ores they mine in Canada, but Inco's cobalt refinery is located in Wales and Falconbridge's is in Norway. Sherritt Gordon has a nickel refinery in Canada, but the feed for that refinery comes from many sources.

Inco smelts and refines nickel sulfide ores in Canada. An impure cobalt oxide is separated in its Canadian operations, then shipped to Clydach, Wales for final processing and packaging. Nickel matte from a laterite operation in Indonesia, which began to be produced in the 1970s, is also processed in Wales, with cobalt again being recovered as oxide. The Clydach refinery produces a variety of cobalt chemicals, but oxide is the starting point for all of them. Cobalt capacity for all products in the mid-1970s was about 700 to 1,000 metric tons annually.

Falconbridge mines and smelts nickel ores in Canada, then ships its nickel-copper matte to Norway for refining. Falconbridge also processes small quantities of matte from Western Platinum Mines in South Africa. In the 1970s this refinery had an annual capacity of about 900 to 1,000 metric tons, producing high-quality electrolytic cobalt.

*Nickel laterites, weathered nickel ores generally found in warm, moist climates, are often referred to as oxides. Important types include limonites (low nickel/cobalt ratio, low nickel content) and garnierites (high nickel/cobalt ratio, high nickel content). Garnierites are silicates.

Sherritt Gordon Mines is a small Canadian nickel producer whose only nickel mine closed in 1976. The nickel refinery has a cobalt circuit that produces hydrogen-reduced powder, a technology that Sherritt Gordon pioneered. Feed for its hydrometallurgical nickel and cobalt refineries historically included mixed nickel-cobalt sulfides from both Impala Platinum in South Africa and Western Mining in Australia. Sherritt Gordon also processed nickel matte imported from Western Mining Corporation in Australia as a major nickel source. Cobalt capacity in the mid-1970s was about 500 metric tons annually.

JAPAN, PHILIPPINES, AND AUSTRALIA

In the mid-1970s a considerable amount of cobalt began to come from the Pacific region. Lateritic nickel operations in the Philippines and Australia came into production in that period. The Greenvale joint venture in Australia is a relatively low-grade nickel laterite that produces nickel oxide with mixed nickel-cobalt sulfides as a byproduct. Greenvale has a long-term sales contract with Nippon Mining Corporation in Japan. Mine production began in 1975, with appreciable amounts first being produced in 1976.

Marinduque Mining and Industrial Corporation also began producing in 1975, with the first major cobalt production occurring in 1976. Marinduque's orebody is the lowest grade laterite currently in production in the noncommunist world,* so its operating costs have been high since it first opened. The project uses Sherritt Gordon's technology to produce nickel, and sells its mixed nickel-cobalt sulfides to Sumitomo Metal Mining in Japan. Sumitomo also gets minor amounts of cobalt refinery feed in the form of residues from its nickel refinery. Although neither operation reached full capacity before 1977, the current capacities are essentially the same as the design capacities for both of the Japanese cobalt refineries (Table 2-4). Both refineries produce electrolytic cobalt, but Sumitomo produces minor amounts of cobalt chemicals as well.

Western Mining Corporation mines, concentrates, and smelts nickel sulfide ores in Australia.. Some nickel matte is exported to Sumitomo, which recovers the relatively small amount of cobalt contained in this matte. In the mid-1970s Western Mining shipped matte from its Windarra mine to Sherritt Gordon for refining, but overall the company has refined most of its nickel matte in Australia. Mixed nickel-cobalt sulfides from the refinery are shipped to Sherritt Gordon for cobalt recovery.

FRANCE

In the mid-1970s France had one cobalt refiner, Metaux Speciaux, a subsidiary of Pechiney Ugine Kuhlmann (PUK) that processes cobalt arsenide concentrates imported from Morocco. The concentrates are roasted, then leached and

*Typical analysis is 1.17 percent nickel and 0.125 percent cobalt.

purified, and cobalt is electrowon from a chloride circuit. Cobalt oxide and chloride are produced from the spent electrolyte. Arsenic and gold are produced as byproducts. The nominal capacity of this plant is about 1,500 metric tons annually, but production in recent years has been well under 1,000 metric tons per year. In the mid-1970s output was typically in the range of 700 to 800 metric tons annually. This refinery is the only one in the world with the capability to process the Moroccan concentrates, and it can process little else.

Much of the cobalt produced by Metaux Speciaux is consumed internally by affiliates. PUK's operations have been in flux in the last decade, but its subsidiaries at times have included firms producing cemented carbides, tool steels, and gas turbine alloys and components (Howmet Turbine Components in the United States).

SOUTH AFRICA

The three South African platinum producers all recover nickel, copper, and cobalt as byproducts. All three companies smelt concentrates to a nickel-copper matte. Rustenburg Platinum Mines, the largest platinum producer, has its concentrates smelted by an affiliate, Matthey-Rustenburg Refiners (MRR). In the mid-1970s MRR refined some of its own matte, without recovering cobalt, and shipped the rest to Amax. Impala Platinum, the second largest producer, uses Sherritt Gordon's process to refine its matte. In the 1970s Impala shipped mixed nickel-cobalt sulfides to Sherritt Gordon for refining. Western Platinum, by far the smallest producer, ships its matte to the Falconbridge refinery in Norway.

UNITED STATES

No cobalt was produced in the United States between 1972 and 1974. About 150 to 300 metric tons of cobalt had been recovered annually as a byproduct of magnetite mining in the old Bethlehem Cornwall operation in Pennsylvania, but production from that source ceased in 1971. In the early 1970s Amax purchased the old Freeport Nickel refinery in Louisiana, originally built to process nickel laterites from Cuba. The refinery had been forced to shut down less than one year after it began operations at the beginning of the 1960s, due to the revolution in Cuba, and had been sitting idle for the next decade. Amax rebuilt the plant so that it could handle nickel feed materials from a variety of sources, generally in the form of nickel matte. Low-level operations began at the end of 1975, and full capacity had still not been achieved in 1978. The original sources of refinery feed for the Amax refinery included nickel-copper matte from Botswana (an operation in which Amax is a minor partner), nickel-copper matte from Matthey Rustenburg

No recoverable cobalt has been mined in the United States since the Bethlehem Cornwall operation closed. In the 1950s cobalt had also been produced in the Blackbird Mine (Idaho) and the Madison Mine (Missouri), but both of these operations closed down after subsidized deliveries under the Defense Production Act ended. Blackbird closed in 1959, and Madison in 1961.

OTHER

Minor sources of cobalt in the mid-1970s included Botswana, Zimbabwe, Indonesia, and New Caledonia. Botswana is a minor source of cobalt, exported in nickel-copper matte produced from sulfide ores. All of its matte in the 1970s was exported to Amax in the United States. RTZ and Anglo-American both operate small nickel sulfide mines, smelters, and refineries in Zimbabwe (Rhodesia). Cobalt recovery from this source is very minor, and all refining is done outside Zimbabwe. Indonesia became a relatively important producer of nickel in the 1970s, all from nickel laterites, but virtually the only cobalt recovered from these ores is produced by Inco in its Clydach refinery. The ores shipped to Japan are processed into ferronickel. Matte from SLN's operation in New Caledonia began to be shipped to AMAX in the United States in 1975.

OTHER CAPACITY

Information on some of the other cobalt capacity in the noncommunist world is summarized in Table 2-5.* This capacity generally depends on finished cobalt in some form as feed, so it was not included in Table 2-4.

COBALT DEMAND

The major uses of cobalt in the noncommunist world are in superalloys, magnetic alloys, cemented carbides, tool steels, catalysts, and salts and driers. Data on cobalt consumption by use are available only for the United States and Japan. Differences in the distribution of cobalt consumption across end uses in the United States and Japan are striking. For other countries, even total consumption data are not generally available.

U.S. DEMAND

Data on U.S. consumption of cobalt by use appear in Table 2-6. Over the 1970s, superalloys, magnets, and salts and driers provided the three most important uses for cobalt, with cutting and wear-resistant materials (cemented and sintered carbides), welding and hardfacing materials, tool steels, and catalysts being less important. Data on cobalt consumption by form are summarized in Table 2-7. Metal, either powder or electrolytic cathode, is the most commonly used product. Consumption of cobalt in the form of purchased scrap was minimal in the mid-1970s.

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*The extra-fine powder operations in the United States are relatively new, and were not in production in the 1972-1976 period.

Table 2-5

OTHER NONCOMMUNIST COBALT CAPACITY, DECEMBER 1982

Country	Company	Nominal Capacity (Metric Tons)	Product	Comments
Belgium	Metallurgie Hoboken Overpelt	1,100	Extra fine powder	Primary input-cobalt from Zaire
		7,300	Oxide and salts	Primary input-cobalt from Zaire
Federal Republic of Germany	Hermann C. Starck	200	Extra-fine powder	
United States	Carolmet	450	Extra-fine powder	Primary input-cobalt from Zaire
	GTE Sylvania	80	Extra-fine powder	From scrap

SOURCE: Contractor estimates.

Table 2-6

U.S. CONSUMPTION OF COBALT BY USE
(Million Pounds)

Year	Super-alloys	Magnets	Cutting and Wear-Resistant	Welding and Hardfacing	Tool Steels	Other Metal-lurgical	Catalysts	Salts and Driers	Other	Total
1970	2.32	2.37	1.40	0.18	0.53	1.78	0.40	2.62	0.36	13.37
1971	1.98	2.28	1.23	0.25	0.32	1.25	0.47	2.74	0.44	12.50
1972	3.01	3.44	1.27	0.20	0.36	1.59	0.70	2.69	0.54	14.13
1973	3.28	4.30	2.51	0.39	0.52	1.85	1.15	3.57	0.64	18.74
1974	4.09	3.46	2.58	0.42	0.69	1.72	1.38	3.64	0.53	18.86
1975	2.26	2.03	1.40	0.48	0.29	1.31	1.11	2.87	0.47	12.79
1976	2.78	3.53	1.59	0.52	0.22	1.74	1.45	3.99	0.33	16.48
1977	3.71	3.48	1.43	0.42	0.31	1.36	1.29	3.78	0.30	16.58
1978	4.30	3.77	1.84	0.73	0.38	1.36	1.62	5.40	0.32	19.99
1979	5.28	3.27	2.12	0.44	0.41	1.03	1.88	1.79*	1.18*	17.40*
1980	6.29	2.27	1.34	0.62	0.32	0.52	1.66	1.41*	0.90*	15.32*
1981	4.20	1.69	1.08	0.49	0.17	0.43	1.28	1.44*	0.90*	11.68*

*The definitions of and reporting practices for the chemical categories changed in 1979. As a result, the chemical end-use and total consumption data are not comparable with those for earlier years.

SOURCE: U.S. Bureau of Mines. Minerals Yearbook (Annual) and Mineral Industry Surveys. Washington, D.C.: U.S. Government Printing Office.

Table 2-7

U.S. CONSUMPTION OF COBALT BY FORM, 1972-1981
(Thousand Pounds of Contained Cobalt)

Form	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Metal	10,509	14,240	14,420	9,202	11,706	11,547	12,823	12,006	10,825	7,450
Oxide	733	668	536	372	462	426	467	704	441	557
Purchased Scrap	197	264	270	342	329	507	1,036	1,170	1,183	972
Salts and Driers	2,691	3,569	3,635	2,871	3,985	3,778	5,399	3,254	2,475	2,421
Other Forms	*	*	*	*	*	319	269	268	397	280
TOTAL	14,130	18,741	18,861	12,787	16,482	16,577	19,994	17,402	15,321	11,680

*Included in purchased scrap.

SOURCE: U.S. Bureau of Mines. Minerals Yearbook. Various issues. Washington, D.C.: U.S. Government Printing Office.

In our view the most reliable data on U.S. consumption are the reported consumption data of the U.S. Bureau of Mines. Apparent consumption data can also be located or constructed, but they suffer from several problems. One is that the cobalt export data available make no distinction between virgin cobalt and cobalt scrap, so that a serious question exists concerning how the export data should be used.

The reported consumption data are not without problems, either. Reporting categories and techniques change from time to time. One of the most important changes occurred in 1979, when the reporting practices for the chemical industry changed very substantially. In the mid-1970s cobalt was counted in consumption if it was used to produce cobalt salts and driers in the United States, and again if these salts and driers were themselves consumed in the United States. The change in reporting that took place in 1979 was designed to eliminate this double counting, but it makes the series for consumption in the chemical and "other" categories, as well as for total consumption, inconsistent over time. The reported consumption data for cutting and wear-resistant materials are also suspect since 1979, since they exhibit a totally different pattern than the same data for tungsten.

SUPERALLOYS

The major use of superalloys is in gas turbines for either jet engines or industrial applications. Some alloys that would normally be classified as superalloys are used in implanted medical prosthetic devices, such as artificial hip joints. Superalloys require high-quality cobalt.

As far as cobalt is concerned, superalloys can be classified as cobalt-base (40 percent or more cobalt), cobalt-bearing nickel-base (8 to 20 percent cobalt), and cobalt-free nickel-base. The cobalt-base and nickel-base alloys consume about the same amount of cobalt, because the lower cobalt contents of the latter are offset by their much higher production. Cobalt is used in superalloys because it provides oxidation and sulfidation (hot corrosion) resistance at elevated temperatures. Additionally, cobalt-base alloys can be air-melted, and ones with low carbon contents are easily weldable. Nickel-base alloys, whether or not they contain cobalt, must be vacuum-melted and generally are not weldable. They usually have greater rupture strength than cobalt-base alloys at elevated temperatures, and if coated appropriately they can often provide acceptable resistance to corrosion. The most common coatings are complex alloys of nickel, aluminum, chromium, and yttrium, deposited in extremely thin layers. Oxide dispersion-strengthened (ODS) alloys derive their strength less from composition than from stabilization of structure by the dispersion of fine oxides through the alloy. They need not contain cobalt. Costs for ODS alloys currently are quite high, compared with those of superalloys, so they have found only limited applications to date. Like the nickel-base superalloys, they require coatings to provide adequate corrosion resistance.

MAGNETS

Permanent magnets made with cobalt are generally superior to other magnets because cobalt is the strongest magnetic element. Cobalt increases the saturization magnetization of iron and has the highest Curie temperature known. The most commonly used magnetic materials are aluminum-nickel-cobalt alloys, collectively known as Alnicos. The most important of these is Alnico V, containing 24 percent cobalt. Other magnetic materials containing cobalt include Remalloy, Permendur, Vicalloy, cobalt-rare earths (usually cobalt-samarium), and chromium-iron-cobalt alloys (Chromindur). In any given application, these last two types of alloys use less cobalt per unit of magnetic strength. Many magnetic alloys can use cobalt metal of relatively low quality.

A number of tradeoffs must be made when magnetic materials are specified for any given application -- magnetic strength, size of magnet, operating conditions, and cost. Ceramic magnets are significantly cheaper than Alnicos, but they must be substantially larger to provide the same magnetic strength, and their performance varies markedly with temperature changes, such as seasonal variations in ambient temperatures in temperate regions.

Major uses for cobalt magnets in the 1970s included loudspeakers, particularly for televisions and radios, watt-hour meters, automobile speedometers, and specialized instruments. Ceramic magnets had already taken many markets from Alnicos since they were first introduced in the late 1950s, but their relative markets had stabilized reasonably well by the mid 1970s.

CUTTING AND WEAR-RESISTANT MATERIALS

Cobalt is used in cutting and wear-resistant materials as a binder for tungsten carbides and mixed carbides. Tungsten carbide powder, and lesser amounts of tantalum, titanium, and other carbide powders, are mixed with powders in the iron group (cobalt, iron, and nickel) and sintered to form cutting tools, drill bits, and so forth. All of the iron-group metals can form a matrix to bind the carbides, but cobalt is by far the best binding agent known. Cobalt has a unique wetting ability that makes its use, in amounts of about 7 to 12 percent by weight, highly desirable. These materials use extra-fine cobalt powder, which is the most expensive form in which cobalt can be purchased commercially.

WELDING AND HARDFACING MATERIALS

Hardfacing materials are welded onto base materials to provide a layer resistant to abrasion and corrosion, particularly where lubrication is not possible. Engine valves provide a major use for hardfacing alloys, but a

number of other applications are important as well. Over 15 hardfacing alloys are commonly used to provide selected combinations of shock resistance, corrosion resistance, hardness, and so forth in special applications. Hardfacing alloys are most commonly applied in the form of welding rods, but plasma and other spraying techniques are used as well. The most important cobalt-bearing alloys used in hardfacing have cobalt contents ranging from 45 to 65 percent.

TOOL STEELS

Tool steels constitute a relatively minor use for cobalt in the United States, particularly in comparison with Europe. High-speed tool steels are the most important as far as cobalt is concerned. They retain cutting ability even at cutting speeds so hot that the tools reach a dull red heat. Carbide-forming elements, such as tungsten, molybdenum, and vanadium, give high-speed steels this property. Cobalt is added to some high-speed steels to improve hot hardness even further. Hot work and cold work tool steels have much lower cobalt contents. Maraging steels, introduced in the 1960s for aerospace applications, are now used for dies and in structural applications. Firm data on cobalt consumption in maraging steels are not available, but in the mid-1970s it was probably in the range of 200,000 to 400,000 pounds of cobalt annually.

CATALYSTS

Cobalt is used in a number of catalytic operations. Cobalt-molybdenum catalysts on an alumina carrier are used widely to remove sulfur and heavy metals from petroleum fractions. Molybdenum is the active catalyst in the reaction, and cobalt acts as a promoter. Nickel-molybdenum catalysts have similar properties, but they also have drawbacks. They must operate at higher temperatures and pressures, and they also consume more hydrogen (in the form of natural gas) to convert sulfur in the oil to hydrogen sulfide gas. Some existing desulfurization reactors cannot use nickel-molybdenum catalysts because the reactors were not designed to operate under the severe environments that would be needed. Other reactors may use nickel-molybdenum catalysts if their performance is satisfactory and the operating cost disadvantage is outweighed by the price differential. In the mid-1970s little use was made of nickel-molybdenum catalysts.

Cobalt catalysts are also used in the production of isooctyl alcohols (for manufacturing polyvinyl chloride) and unsaturated polyesters. The minor catalytic uses of cobalt are not generally subject to substitution, because existing plants were built to carry out certain reactions that require cobalt. In some cases new plants could be built that would use different reactions to make the same products, and these reactions would not require cobalt.

SALTS, DRIERS, AND OTHER CHEMICALS

Oxides, inorganic salts, and organic salts of cobalt are used widely. Organic cobalt salts, such as cobalt napthenate and oleate, are used as driers in inks, varnishes, and oil-base paints. Cobalt is primarily a surface drier, so it is normally used with other driers, such as manganese, to promote fast, even drying of paint films and the like. The same types of compounds are often used to speed the curing time for certain plastics.

Inorganic salts and oxides find wide applications in pigments, animal feed additives, electroplating, ground coat frit, and other uses. None of these uses is major. Cobalt pigments provide deep blue colors for ceramics. Cobalt is a constituent of vitamin B-12, and cobalt is often added to feed supplements for cattle and other livestock that graze in areas deficient in the compound. Very small quantities of cobalt are used in this application. Since the end of the nickel shortage in 1969 and the return of the free market nickel price to a level below that for cobalt, very little cobalt has been used in electroplating. Cobalt and nickel have very similar plating properties, but platers have little incentive to use cobalt when it costs more than nickel. Cobalt and nickel oxides are used in ground coat frit to make porcelain enamel adhere to metallic surfaces, such as for appliances, cookware, and so forth.

Cobalt chemicals, including those used to produce catalysts, can be made from any form of cobalt, including oxide, powder, and cathode of almost any quality.

FOREIGN CONSUMPTION

Data on foreign cobalt consumption by use are available only for Japan (Table 2-8), where magnets are the most important application. Estimates of total cobalt consumption are available for some other countries (Table 2-9). No consistent data on cobalt consumption outside the United States and Japan are available after 1976. Tool steels and carbides are more important in Europe than in the United States. The growth, substitution, and conservation possibilities by use are generally the same in other countries as in the United States.

The quality of the consumption data outside the United States is generally quite poor. The reported cobalt consumption data for Japan, presented in this report, are the best source of information on consumption by use outside the United States. Unfortunately, coverage of consumers seems to be considerably worse in Japan than in the United States. The reported consumption data are consistently well below the apparent consumption data.

For other countries, apparent consumption data are the best that can be obtained. Some countries, like France and the United Kingdom, report on cobalt consumption by the steel industry, but precisely what that might include is never clear.

Table 2-8

COBALT CONSUMPTION BY USE -- JAPAN
(Metric Tons)

Year	Magnets	Special Alloys and Steels	High-Speed Steels	Heat-Resistant Alloys	Cemented Carbides	Other	Total
1970	2,395	NA	265	251	127	410	3,448
1971	1,315	NA	180	231	91	382	2,199
1972	1,545	NA	186	363	108	357	2,558
1973	2,125	NA	525	527	171	575	3,924
1974	1,244	NA	351	627	154	431	2,806
1975	836	NA	171	455	85	432	1,979
1976	1,550	NA	201	490	128	627	2,996
1977	1,117	NA	252	461	112	517	2,459
1978	1,116	NA	232	218	112	740	2,388
1979	872	420*	NA*	NA*	144	788*	2,227
1980	667	385*	NA*	NA*	165	695*	1,912
1981	457	265*	NA*	NA*	153	636*	1,511

*Definition of categories in available data sources changed after 1978.

SOURCE: Ministry of International Trade and Industry. Yearbook of Nonferrous Metals, Demand and Supply Statistics (Annual).

Table 2-9

COBALT CONSUMPTION -- OTHER COUNTRIES
(Metric Tons)

Year	United Kingdom	France	West Germany	Other Europe	Other Non-communist	Total
1970	3,224	1,525	2,600	2,369	985	10,703
1971	3,028	1,242	1,739	2,154	863	9,026
1972	1,833	1,039	1,805	2,106	1,005	7,788
1973	2,387	1,314	2.328	2,453	1,411	9,893
1974	3,677	1,693	2,510	2,887	1,371	12,138
1975	2,772	1,495	1,798	2,168	1,198	9,431
1976	1,503	1,168	2,261	2,494	1,357	8,783

SOURCE: Berlin: Deutsches Institut fur Wirtschaftsforschung; and Hanover: Bundesanstalt fur Geowissenschaften und Rohstoffe. 1978. Kobalt.

DEPENDENCE ON ECONOMIC ACTIVITY

Different sectors of the cobalt market have grown with different sectors of the economy. Cobalt demand in superalloys has depended heavily on both civilian and military aerospace programs. Strong demand for civilian and military jets means strong demand for cobalt in superalloys. The demand for cobalt in magnets has depended more heavily, but certainly not exclusively, on the consumer durables sector of the economy, for television receivers, stereo loudspeakers, car radios, and so forth. The cutting and wear-resistant materials (carbides) and tool steels rely very heavily on metal-cutting operations, which means for the most part investment goods. Tungsten carbides are also used in oil drilling and mining operations, however. The catalytic uses have tended to grow in fits and starts, depending on when new catalytic reactors of one type or another have been brought into production and charged with their catalysts. Other uses have grown roughly in line with overall industrial production.

OTHER ISSUES

Other issues that concern the cobalt market include recycling and waste disposal, stocks, and government policies. Of these, only government stockpile policies were important in the mid-1970s.

RECYCLING AND WASTE DISPOSAL

Recycling and waste disposal for cobalt in the period 1972-1976 consisted almost entirely of the latter, with none of the former. Part of the reason was that with a relatively low cobalt price, consumers and processors had little incentive to try to reduce cobalt losses in fabrication.

Considerable quantities of cobalt-bearing scrap was generated in the production of superalloys and the fabrication of parts from these alloys, but little of this cobalt was recovered. Mixed alloy scrap was generally collected and sold to scrap merchants, who then sold it to the steel industry as a source of chromium and nickel units (the cobalt counting as nickel in this regard, as with ferronickel). The steel industry then used the scrap in producing stainless steels and nickel-chromium alloy steels. Trying to segregate the alloys by type and remelt the scrap, or reprocess it by hydrometallurgical methods to recover the constituent metals separately, was simply impractical.

Similar conditions held true with the other major uses, although they all produce much less scrap than does the superalloy industry. Segregating and using new cobalt scrap was simply not economically feasible.

The situation with old cobalt scrap was much the same. Many of the uses for cobalt, unlike those for steel, copper, aluminum, and many other materials, are rather dissipative. Recovering a few ounces of cobalt from old magnets when stereo speakers are junked is simply not practical under all but the most extreme circumstances. The cobalt used in driers, pigments, feed additives, and most other chemical applications is not recyclable under any circumstances. The cobalt used in many catalytic applications could in theory be recycled, particularly in the hydrodesulfurization catalysts, but prices in the 1970s were too low to make such recycling worthwhile. The situation with tool steels and cemented carbides was somewhat different. Many of the products made from these materials are used in relatively high volume, and could be collected for recycling fairly readily if circumstances warranted. Generally, however, they did not. Old gas turbines were certainly a potential source of cobalt, but turbine parts were so contaminated in service that no economic way had been found to take them apart and recover the metals in them.

PRIVATE STOCKS

Essentially no information is available on cobalt stocks outside the United States and Japan. The Bureau of Mines publishes monthly information on consumer stocks of cobalt, which are probably about as accurate as the data on reported consumption. Annual data on total industry stocks, which include producer stocks, are also published. MITI publishes data on cobalt stocks in Japan, for consumers, producers, and dealers, but these are likely to be no more accurate than the Japanese consumption data. Table 2-10 lists cobalt stocks held by U.S. consumers, industry, and government and Japanese producers, dealers, and consumers for the years 1972-1981.

In the United States consumer stocks have generally amounted to about one month of consumption, while industry stocks are in the range of 2.5 months of consumption.

GOVERNMENT POLICIES

Essentially only the United States had anything resembling a government policy toward cobalt in the mid-1970s. Many government agencies, in the wake of the first OPEC exertion of market power in 1973, became worried about similar actions in other markets, including cobalt. As a result, many studies of cobalt were performed from 1974 to 1976, and research programs were instituted to examine the feasibility of producing cobalt and other metals from domestic ores. None of these programs had any real effect on the cobalt market at the time.

Table 2-10

COBALT STOCKS HELD BY U.S. CONSUMERS, INDUSTRY, AND GOVERNMENT AND JAPANESE PRODUCERS, DEALERS, AND CONSUMERS, YEAR END, 1972-1981
(Metric Tons)

	United States			Japan			
	Consumers	Industry*	Government**	Producers	Dealers	Consumers	Total
1972	541	2,057	32,432	NA	NA	NA	NA
1973	1,112	4,166	28,545	NA	NA	NA	NA
1974	929	4,295	24,492	10	124	914	1,048
1975	817	3,148	21,614	48	38	531	617
1976	1,442	4,021	18,575	75	145	902	1,122
1977	1,696	3,568	18,552	91	197	631	919
1978	1,990	2,731	18,509	144	21	375	540
1979	1,538	3,473	18,507	338	24	478	839
1980	1,152	3,405	18,507	240	12	428	679
1981	640	2,722	18,507	334+	17+	437+	788+

*Producer plus consumer stocks.

**Total inventory.

+End of January 1981.

SOURCES: U.S. data obtained from U.S. Bureau of Mines, Minerals Yearbook and Mineral Commodity Summaries, various issues. Washington, D.C.: U.S. Government Printing Office. Japanese data from Ministry of International Trade and Industry.

One U.S. government policy did, however, affect the cobalt market. As of 1975 the U.S. strategic stockpile of cobalt amounted to about 40 million pounds, and the objective was 11 million pounds. The GSA had been selling approximately 6 to 9 million pounds of cobalt annually in the 1970s, until the sales were halted in 1976, after the civil war in Angola cut off the Benguela railway in late 1975. In late 1976 a new stockpile objective of about 85 million pounds was announced. This meant that the United States had turned overnight from being a supplier of about 10 percent of the noncommunist world's cobalt to being a potential purchaser of the same magnitude. Cobalt producers had expected the GSA sales to continue at their early-1970s level for another five years or so, when they were suddenly halted. This definitely upset the balance between supply and demand in the market.

3

IMMEDIATE IMPACTS OF THE COBALT SHORTAGE, 1978-1979

COBALT IN 1977

The cobalt market in 1977 was much the same as it had been in 1976 -- supply, demand, and prices were little different in the two years. A flurry of concern was raised in early 1977 when insurgents from neighboring Angola invaded Zaire's Shaba Province, where the copper and cobalt operations are located. The insurgents had fled to Angola after losing their bid for an independent Katanga (i.e., Shaba) in the mid-1960s. Their invasion was quickly routed, and they never even reached the mining operations centered around the town of Kolwezi in Western Shaba. This invasion caused a flurry of excitement, but it had no other effects on the cobalt market.

SUMMARY OF 1978-1979

The situation began to change in 1978. In early 1978, the producer price of cobalt cathode was $6.85 per pound, and demand had been relatively weak for several years. Zaire had produced at low levels in 1976 and 1977, partly to prevent inventories from accumulating and partly due to physical and financial problems.

In 1978, demand began to increase very rapidly, due to a moderately strong world economy and a boom in the aerospace industry. A free market began to develop for cobalt from minor producers and excess consumer stocks, with prices creeping upward. At the end of April, sales agents for Zaire announced the institution of an allocation program for cobalt, because they did not have enough cobalt to satisfy the surging demand. Consumers were to be limited to 70 percent of their purchase in 1977.

The situation was made worse by the fact that the U.S. government was no longer a source of supply for the cobalt market in general and the United States in particular. Stockpile sales had been a significant fraction of domestic consumption in the early 1970s, and the world's cobalt producers had expected these sales to continue into the early 1980s. That 10 percent of the noncommunist world's supply disappeared after 1976 did not matter in a slack market, but it certainly made a difference when demand boomed.

Shortly after the allocation program was announced the market exploded. In early May Zaire's Shaba Province was invaded by the same insurgents who had invaded in 1977. This time they were more successful, taking the town of Kolwezi. They were driven out within two weeks, and they left the production facilities around Kolwezi only slightly damaged. The only real damage involved flooding in the Kamoto underground mine. The open pit mines, the Kamoto and Kolwezi concentrators, and the Luilu hydrometallurgical plant were all unharmed. Operations in other mining areas, which produce about half of Zaire's cobalt, were completely unaffected. About 130 expatriate workers were reportedly killed, causing many others to leave the country within the next few months. The sudden departure of several hundred skilled workers, combined with the existing shortages of fuel, supplies, and parts, exacerbated the already difficult position of Gecamines.

The brief occupation of mining and processing centers by insurgents raised consumers' concerns over the continued availability of cobalt. Although the production facilities in Zaire had suffered minimal damage, these concerns and the growing demand for cobalt kept prices spiraling upward. The free market price peaked at over $40 per pound in late 1978, after which it began to decline gradually. The producer price was raised, in a series of steps, to $25 per pound in February 1979 --four times its level 12 months earlier. At the end of 1979 the producer price was still $25 per pound, but the free market price had slipped to about $23 per pound.

The market responded to these price increases, gradually. Cobalt is generally recovered as a byproduct of nickel or copper operations, so most producers had limited options in the short run. Several new cobalt refineries were rushed into full production; construction, and in some cases minor production, had been started before 1978. Other producers modified their operations to mine ores with higher cobalt contents, to improve cobalt recoveries in concentrating and refining, and to eliminate bottlenecks in processing. Cobalt production outside Zaire increased substantially from 1977 to 1979. Work began on new operations as well.

Demand, as well as supply, responded to the high prices. Substitution and conservation efforts were made in almost all of cobalt's uses, some successfully and others less so. Recycling became an important source of cobalt.

MARKET STRUCTURE

One important effect of the shortage of 1978-1979 was that Zaire to a great extent lost control of the cobalt market. Other producers announced a series of price increases, and a major dealer market for cobalt developed. No longer was the cobalt price dictated by people in Brussels, with virtually all of the noncommunist world's cobalt trading hands at that price. This shakeup in the cobalt market had implications for the future as well -- producers who charged free market prices when the market was tight found that they also had to charge free market prices when the bubble burst. This hastened the collapse of the market when the shortage ended.

SUPPLY RESPONSE

As noted above, the immediate response of cobalt producers to the rapid rise in cobalt prices was limited by the byproduct nature of cobalt production. All attempts to increase production took time. The changes in cobalt production and capacity that occurred in the 1978-1979 period are discussed below.

ZAIRE

The boom in demand coupled with concern over events in Zaire were the major causes of the cobalt shortage in 1978-1979; Zaire did not react to the situation so much as unwillingly contribute to it. Cobalt production from newly mined material was limited in 1978 and 1979 to about 10,000 metric tons per year, with the stockpiled cobalt hydroxide permitting total production to reach 13,000 to 14,000 metric tons in those years. Shortages of cash and expatriate workers contributed to shortages of fuel for mining trucks, spare parts for equipment, operating supplies, and skilled labor. The high cobalt prices in 1978 and 1979 did not immediately ease any of Zaire's problems, although it did help them eventually. Work continued on the DIMA concentrator and on the Inga-Shaba power line, but other parts of the P2 expansion plan and of the Tenke-Fungurume project were placed on indefinite hold.

ZAMBIA

The situation in Zambia was somewhat different. As luck would have it, RCM finished work on its new Chambishi refinery in late 1978, permitting production near capacity levels to be carried out in 1979. This refinery is a roast-leach-electrowin plant, much like the Rokana I plant of NCCM and the Luilu plant of Gecamines. It has a nominal capacity of 2,400 metric tons annually. Much of the plant was based on the existing cobalt operation at Chambishi. The major changes involved the addition of a new roaster and a cobalt tankhouse. The leaching circuits and a copper tankhouse already existed. The quality of the cobalt from this refinery was poorer than had been anticipated, but in 1978 and 1979 cobalt quality was of much less concern than availability.

Partly as a result of the cobalt shortage, NCCM announced in mid-1979 plans to construct a new cobalt refinery and to refurbish its existing refinery. These plans might have gone ahead even without the cobalt shortage, although that is not clear. NCCM had announced at the beginning of 1979 that its Nchanga open pit mine, one of its largest sources of copper, had a cobalt-rich zone whose mining would begin within the next few years in the normal course of mine development. NCCM faced several options concerning cobalt recovery, and eventually decided to build a new roast-leach-electrowin plant, virtually a twin of that completed by RCM. This plant would have a capacity of 2,600 metric tons of cobalt annually. At the same time NCCM would modernize its existing refinery, primarily by increasing its copper tankhouse capacity to permit it to operate at its nominal capacity. NCCM also considered the possibility of cleaning copper slags in order to increase cobalt production. Slags arising from current copper operations could be processed, as could slags accumulated over the previous 40 years. The old copper smelter slags have an average cobalt content of about 0.6 percent, although some zones in the slag heaps are much richer and others much leaner.* Cleaning old slags might produce 5,000 to 10,000 metric tons of cobalt annually, for 10 to 20 years. Eventually NCCM decided to hold off on the slag-cleaning operations, and to concentrate on the new cobalt refinery and copper operations already in planning.

Both companies managed to increase cobalt production significantly by improving cobalt yields. Much of the cobalt in Zambia had been lost to tailings and to the copper concentrates, from which it was not recovered. RCM increased its recovery into cobalt concentrates from 60 percent in 1977 to 70 percent in 1979. NCCM realized a similar gain, from 30 percent in 1977 to 34 percent in 1979. A further improvement, to 60 percent, was planned, and recoveries of almost 50 percent were achieved in 1980. The companies also tried to increase their yields in the cobalt refineries, up from the 70 percent level, but they did not succeed in doing so.

*Similar slags are found at the Lubumbashi smelter in Zaire, but Gecamines has no incentives to recover cobalt from them.

The additional material coming from the new RCM refinery had to be marketed, so Memaco, the national sales company for Zambian copper, cobalt, and other copper industry products, made a concerted effort to diversify its customer base. In practical terms that meant selling cobalt in the United States, rather than just in Europe.

Zambia, and also Zaire, experienced a worsening of its transportation problems in October 1979, when a major bridge on the Tazara railroad was blown up, allegedly by Rhodesian commandos. With the loss of the rail link to Dar es Salaam, Zambia increased shipping on the southern route, through Rhodesia to South Africa, and used trucks for transportation to Dar. Although breaks in the transportation network have only minor direct impacts on cobalt deliveries, since cobalt can be flown out of Zaire and Zambia rather easily, they greatly affect exports of copper and imports of equipment and supplies. The bridge was repaired after about a year.

FINLAND

Finland also increased its cobalt production in 1978-1979, but this had little to do with the cobalt shortage. Before the shortage started Outokumpu Oy had planned to expand the capacity of its refinery from about 1,000 metric tons annually to about 1,450 metric tons, using old copper furnace residues from the German Democratic Republic as a source of cobalt. Work on the expansion was completed during the cobalt shortage. The additional cobalt is returned to East Germany, so the increase in production does not really add anything to noncommunist world supply, except to the extent that it reduces net exports of cobalt to the communist world.

CANADA

The Canadian nickel companies became actively interested in cobalt as a result of the shortage. Sherritt Gordon increased its capacity from 500 metric tons to 600 metric tons at the end of 1979 by eliminating some bottlenecks in the refinery, and planned further increases. In a matter unrelated to the cobalt shortage, Western Mining Corporation closed its Windarra mine in Australia, which eliminated the nickel matte from that operation as feed for Sherritt's nickel-cobalt refinery. In 1978 Sherritt Gordon announced that it had arranged to purchase nickel concentrates from Inco's Fort Thompson, Manitoba operation. This had no real impact on Sherritt Gordon's cobalt production. Sherritt sought out new sources of cobalt, including an assortment of residues and wastes; no information is available on the exact nature of these materials.

Falconbridge increased the capacity of its cobalt refinery in Norway from about 1,000 metric tons to 1,800 by the end of 1979. Falconbridge investigated several new, small sources of feed for the refinery, including certain types of clean alloy scrap and residues; no other information is available on these materials.

Inco had the most ambitious plans. It immediately began to send some of the cobalt residues generated in its Canadian and Clydach cobalt plants to Sherritt Gordon and Falconbridge for toll refining. As a result, cobalt production data for the Canadian companies must be treated with care, because Inco counts this cobalt as part of its own production, as do Sherritt Gordon and Falconbridge. Inco also announced plans to double its cobalt production, by making some slight process changes and by reducing the amount of cobalt lost to nickel slags. By far the bulk of Inco's cobalt is lost in processing. Inco considered a slag cleaning operation in Canada, to recover nickel, copper and cobalt. Although motivated in part by the cobalt shortage, a slag cleaning operation would be part of a major change in Inco's Canadian nickel operations. As such it would take some years to implement after a decision was made to proceed. In addition, it could not be considered too seriously until Inco solved its sulfur emissions problems in Canada. Environmental regulations had begun to restrict the total amount of sulfur that Inco could release into the atmosphere, and given the existing physical plant Inco could meet these restrictions only by operating at well under its nickel capacity. In the relatively weak nickel market from 1975 on this was no great hardship, but Inco will not embark on a major modernization of its Canadian nickel operations until the nickel market improves, and the sulfur emissions problem is solved.

The lateritic nickel operations in Indonesia and Guatemala played a role in Inco's cobalt plans. The small Exmibal project in Guatemala began operations in 1978, shipping nickel matte to Clydach. Stage II of the Soroako operation in Indonesia was expected to come into production within a few years also, likewise providing matte to Clydach. Together these operations would account for several hundred tons of cobalt.

Inco's cobalt production was in fact hampered somewhat by a lengthy strike in its Canadian operations, lasting from September 1978 until June 1979. This reduced the amount of cobalt that could be sent to Clydach. In October 1979 the workers at Clydach went on strike, and stayed out into 1980.

Interest also arose in other sources of Canadian cobalt. Noranda Mines, a large copper and zinc producer in Canada, joined with Agnico-Eagle, a small silver producer, in exploring for cobalt around Cobalt, Ontario. As the name of the town indicates, the region had been a source of cobalt in the past, and small quantities of cobalt had sometimes been recovered from silver mining operations since 1950. Nothing came of this activity.

PACIFIC

The relatively new cobalt-nickel operations in Australia, the Philippines, and Japan continued to increase production in 1978, partly because the cobalt shortage gave them an incentive to do so, and partly because technical problems in the lateritic nickel plants were being solved gradually.

For example, Marinduque had begun mining operations only in 1975, at a very low level, and in 1976 it produced only half of its capacity. From 1977 to

1979 it continued to increase production, as new mineral operations generally do after they first come into production. Marinduque did take two actions directly as a result of the cobalt shortage. In 1978 it renegotiated its sales contract with Sumitomo, signing a new 10-year contract. The new contract called for the mixed sulfides produced by Marinduque to be sold on the basis of the producer prices for nickel and cobalt, with a specified amount of the cobalt to be repurchased by Marinduque at the producer price. Marinduque would then market this material, through metal traders, at free market prices. This new contract increased Marinduque's cobalt revenues considerably when the free market price was above the producer price, as it was in 1978 and through most of 1979. Marinduque also increased the cobalt-nickel ratio in its mixed sulfides, to permit greater cobalt production.

Greenvale likewise attempted to renegotiate its sales contract with Nippon Mining, but with no success. The Greenvale operation continued to move closer to producing at full capacity, like Marinduque. Greenvale selectively mined cobalt-rich zones of its orebody in order to increase cobalt production relative to nickel production.

Western Mining Corporation announced plans to double its mine production of cobalt in the near future, to about 600 metric tons, with an eventual target of about 1,600 metric tons. The company said little else about these plans, such as how production would be increased, and whether Sherritt Gordon would refine the new material as well as the old. The plans seem not to have been carried out to any significant degree.

The Agnew project in Australia began operations in 1979. Its nickel sulfide concentrates are smelted by Western Mining and shipped to Amax in the United States for processing.

The cobalt shortage had essentially no impact on other nickel-cobalt operations in the Pacific. P.T. Nickel Indonesia suspended its plans indefinitely in 1979, due to the continued weakness in the nickel market. New Caledonia, which has the noncommunist world's most extensive resources of both nickel and cobalt, in laterites, saw some continued exploration work and feasibility studies by AMAX and BRGM, the French national minerals organization, but this was unrelated to the cobalt shortage.

FRANCE

In 1978 SLN, the French company that is the largest producer of nickel in New Caledonia, commissioned a new nickel refinery in France. The cobalt recovery circuit in this refinery could produce as much as 600 metric tons of cobalt annually in the form of a cobalt chloride solution. This plant treats nickel matte from SLN's lateritic nickel operations in New Caledonia, some of which was previously processed by Amax. Unfortunately for SLN, in October 1978 a fire destroyed the nickel electrolysis plant of the refinery. Since SLN could not find a market for nickel chloride, which could still be produced in

the plant, it cut back on nickel matte production in New Caledonia and increased ferronickel production. This meant that world cobalt production was not increased by this refinery until the repairs were completed.

SOUTH AFRICA

In 1978 Matthey Rustenburg Refiners announced plans to recover cobalt in its existing nickel refinery. Prior to that all of the cobalt in its refinery had either been lost or had reported to its nickel and had been sold as nickel. In June 1979 MRR commissioned a small cobalt circuit, with an annual capacity of about 100 to 150 metric tons of cobalt contained in cobalt sulfate. This cobalt circuit proved to be a full-scale test for the cobalt circuit planned for the new MRR nickel refinery then under construction. This refinery was being built to treat the material shipped to AMAX.

In 1978 and 1979 interest developed in a large potential source of cobalt in South Africa. Old gold tailings are currently leached and processed to recover gold and uranium. Significant quantities of cobalt are leached as well, then lost in processing. Perhaps as much as 2,000 metric tons of cobalt could be recovered annually from this source. This possibility was investigated by the Anglo-American Corporation. Recovering cobalt from these leach liquors is likely to be relatively expensive, and the high-cobalt tailings will not last indefinitely. Cobalt recovery seems unlikely.

UNITED STATES

AMAX increased its cobalt production up to capacity in 1978-1979, and began to investigate other possibilities for its cobalt. These included upgrading the production facilities at its nickel refinery in order to improve the quality of its cobalt, so it would be useable in most metallurgical operations. AMAX also became interested in the cobalt that was being lost in its large lead-zinc operation in Missouri. The cobalt content of the ores being mined amounts to about 1 million pounds annually, none of which was being recovered. As mentioned above, in 1979 AMAX began to receive shipments of nickel matte from the Agnew project in Australia. It also began to plan for the loss of the matte purchased from SLN and MRR, because these companies, as mentioned above, had either built or were building their own nickel refineries.

In early 1979 Noranda Mines began to consider developing the old Blackbird Mine in Idaho. This mine last operated, not very successfully, in the 1950s. The orebody is complex and highly faulted, averaging about 0.55 percent cobalt in the form of arsenides. Some copper and gold are contained in the ore as well, but they would not make a significant contribution to project revenues. An operation of between 2,000 and 4,000 metric tons was planned.

Part of the problem in the past was with the process and the physical plant. Research undertaken by the Bureau of Mines and by Noranda indicated that both problems could be solved technically. Noranda also maintained that the arsenic in the orebody would not prove to be an environmental problem. One environmental problem did have to be resolved immediately, however. The suspected zone of cobalt mineralization in the Blackbird district extended into the proposed River of No Return wilderness area. Compromises were reached that would permit underground cobalt mining, but not surface mining, in the region.

At about the same time the Anschutz Corporation began to investigate the old Madison Mine in Missouri. This mine, located in the old lead belt of Missouri (as opposed to the new lead belt, where Amax has its Buick operation), operated in the 1940s and 1950s, producing cobalt, nickel, and lead. The ore grades only about 0.25 percent cobalt, with a similar nickel content. An annual capacity of about 1,000 metric tons of cobalt was planned, with a similar amount of nickel. When the mine last operated in the 1950s, its capacity was 635 metric tons of cobalt and 860 metric tons of nickel. Anschutz hoped that the proximity to the lead belt would prove advantageous, with the operations in the new Missouri lead belt able to produce cobalt-nickel concentrates that could be processed by Anschutz. In 1979 Anschutz actually shipped some old cobalt residues from the Madison Mine to Outokumpu Oy in Finland for refining.

In 1979 Metallurgie Hoboken-Overpelt announced plans to construct a plant in North Carolina to produce extra-fine cobalt powder. This would be their first such plant outside Belgium.

OTHER

The only other moderately important development in cobalt supply in the 1978-1979 period involved Uganda. The Kilembe copper mine and smelter in Uganda, operated for many years by Falconbridge, had closed down in the middle of Idi Amin's reign. After he lost control of Uganda, interest arose in processing some cobalt-rich pyrites accumulated over the course of 20 years of nickel operations. The tailings were reported to average 1.4 percent cobalt, with a gross weight variously reported as 100,000 metric tons and 1,000,000 metric tons. Possibilities for the property included: building a roast-leach plant to produce intermediates that could be refined elsewhere; reopening the Kilembe mine and smelter, and constructing a cobalt refinery on the site; and shipping the pyrites as is for processing abroad.

DEMAND RESPONSE

Cobalt substitution and conservation activities by end use were similar in different countries in 1978 and 1979, although the total extent of substitution and conservation depended on the mix of the end uses. This discussion will focus on actions taken in each of the major end uses, with indications where appropriate of major differences by country.

SUPERALLOYS

The aerospace market was very strong in 1978 and 1979, with this strength expected to last through the mid-1980s. The boom was driven by many factors, including strong demand for air passenger and freight travel in the United States and the rest of the world, and the need to replace aging planes in the commercial fleet. The older planes were generally both noisy and inefficient users of jet fuel.

The strong demand for cobalt in aerospace applications led the surge in cobalt demand in 1978, and legitimate concerns by the jet engine manufacturers over the future availability of cobalt contributed to the rise in the free market price.

The jet engine manufacturers themselves could do little to reduce their cobalt consumption in the short run, however. The alloys used in the various parts of a gas turbine are selected for the combinations of strength and corrosion resistance that they provide, at different operating temperatures. Changing such alloys is not a simple matter of making parts from a new alloy and inserting them into the turbine. If potentially acceptable alloys do not exist they must be developed and tested extensively. The final stage of testing includes multimillion dollar qualification programs, to check the long-term performance in simulated flight conditions, including takeoffs, landings, and cruising. These tests can take two to five years.

The situation for land-based gas turbines was somewhat different. The lengthy qualification programs needed to certify a turbine for aircraft use are unnecessary for the land-based turbines. The availability of potential substitute alloys posed the same problem, however.

The jet engine and industrial gas turbine manufacturers were able to make some changes, however. In some cases they had qualified essentially similar versions of an engine for civilian and military purposes, with these engines using different alloys. In such cases direct substitution was possible without resorting to extensive alloy development and testing. Even these substitutions took time to carry out, from 1979 to 1980 or 1981. They amounted to perhaps 10 percent of total cobalt consumption in superalloys.

The gas turbine manufacturers are only the final consumers of most superalloys, although they certainly dictate what alloys will be produced. The alloy melters and fabricators are also very important in determining the total amount of new cobalt needed to produce the parts needed for a given turbine. Their behavior changed considerably as a result of the cobalt shortage, primarily in recycling, which will be discussed below in a separate section.

Improved fabrication methods are another means to conserve valuable alloying metals like cobalt. A number of improved processing methods were studied in 1978 and 1979, although most of this interest was not directly motivated by the cobalt shortage. These processing changes include single crystal alloys, rapid solidification, and hot isostatic pressing. Single crystal alloys are being developed by Pratt and Whitney for use in their jet engines. A turbine blade or vane made from such an alloy will not suffer from weaknesses at grain boundaries, because each component will be constructed from a single crystal. Much greater strength can be obtained with such components. The single-crystal alloys being developed by Pratt and Whitney are cobalt-free, but that is due to the properties required of the alloys, not to the cobalt shortage. Rapidly solidified alloys are cooled extremely quickly so that a combination of metals that would normally separate when cooling is not able to do so. As far as superalloys are concerned, such alloys would normally be produced in the form of a powder, which would then be consolidated into turbine components. Powder metallurgical methods of fabricating products conserve raw materials because the parts can be produced in almost their final form; this is known as near-net-shape processing. Hot isostatic pressing is one method of consolidating metal powders into parts. As with the single-crystal alloys, very little of this work was motivated directly by the cobalt shortage.

The superalloy situation in the United Kingdom was somewhat different than that in the United States. Rolls Royce, the British jet engine manufacturer, uses almost no cobalt-base alloys in its large jet engines. The major engine manufacturers in the United States, Pratt and Whitney and General Electric, do use them. This means that the U.S. manufacturers were affected more by the high prices, and that they had a greater long-run potential to reduce consumption.

MAGNETS

In 1978 and 1979 cobalt consumption in magnets was reduced considerably by substitution. The major shift was from Alnico magnets to ceramic magnets, barium and strontium ferrites, in loudspeakers. Over the course of the two years approximately 70 percent of the Alnicos used in loudspeakers were replaced with ferrites. In general only the largest loudspeakers stayed with

Alnicos, because such loudspeakers would have been too heavy if made with ferrites. The Bell System announced in 1979 that it was switching from Alnicos and Remalloy to Chromindur in various telephone and switching applications, which would substantially reduce its consumption of cobalt.* The possibility of using ferrites in applications subject to temperature fluctuations, such as in car speedometers, was investigated. In all, U.S. cobalt consumption in magnets was cut by about 40 percent as a result of the cobalt shortage.

Much of this substitution is probably irreversible. Because ferrites are cheaper than Alnicos, the potential magnet user must weigh the better properties of the Alnicos against the lower cost of the ferrites and the costs of making any change. In many loudspeaker applications in the past, the cost differential between the ferrites and Alnicos was small enough that the fixed cost of making the change (retooling, redesigning, etc.) was a barrier to doing so. Once the change was made, however, the magnet user has no reason to consider switching back, even if the cobalt price drops below its historical levels. Some substitutions, particularly those involving significant tradeoffs between properties and cost, are not irreversible.

One of the potential ways in which cobalt consumption could be reduced was not exploited in 1978-1979. Cobalt-rare earth magnets have very high cobalt contents, on the order of 65 percent, but they are so much more powerful than the Alnicos that total cobalt consumption can be reduced by half if a cobalt-rare earth magnet replaces an Alnico. Magnet users, however, were understandably reluctant to design a new cobalt-containing product at a time when the cobalt market was still tight and future supplies were considered uncertain. This applied also to potential new users of the powerful cobalt-rare earth magnets. They generally postponed any such plans indefinitely, waiting to see if the cobalt market would stabilize, and at what price.

The situation in Japan was somewhat different. Most of the switch from Alnicos to ferrites had been completed by the mid-1970s, so the Japanese magnet industry, still a large consumer of cobalt, did not have the same potential to reduce consumption during the 1978-1979 shortage.

HARDFACING MATERIALS

Hardfacing alloys were expected to lose some of their markets to nickel alloys, particularly in applications such as automobile engine valves, chain saws, and earthmoving equipment. Users switched to some known nickel alloys, but some new alloys were also developed.

*Development of Chromindur alloys had been started before the cobalt shortage, to reduce fabricating costs for the magnets. The composition of Chromindur II is typical for these alloys: 28 percent chromium, 10.5 percent cobalt, balance iron.

CUTTING AND WEAR-RESISTANT MATERIALS

Some research was devoted to reducing the cobalt in carbide cutting materials, but without great success. Mixed cobalt-nickel binders can be used in place of cobalt binders in some of the less stringent applications, but this substitution was not widely made. The cemented carbide market is one in which users tend to purchase brand names, not specific alloy compositions, so a carbide producer could change the binder in a product without the user's knowing, unless changes in performance became apparent. This seems not to have happened, however.

Considerable research has gone into improving and developing cutting materials, but little of this effort has been devoted to cobalt. Even at $50 per pound, cobalt is a secondary component of the raw materials cost of tungsten carbides and mixed carbides, tungsten being by far the most important. Much of the research has involved ways to recycle carbide tools, to extend their useful lives, and to find low-cost substitutes. All of these activities affect cobalt consumption in this category, but none are appreciably affected by cobalt prices.

The U.S. consumption data for cobalt in cutting and wear-resistant materials are particularly questionable since 1978. Carbide producers and consumers report that the ratio of tungsten to cobalt in carbides has changed little in recent years, but the most current data reported by the U.S. Bureau of Mines for tungsten and cobalt in this consumption category have very different trends. At least two explanations seem possible. First, users may report their purchases of cobalt and tungsten, rather than their actual consumption. Users certainly built up their cobalt stocks in 1978, then started to work them down. Second, some users returning the monthly questionnaires to the Bureau of Mines may confuse the welding/hardfacing and the cutting/wear-resistant categories. If some consumption that should properly be included in the welding and hardfacing category is instead included in the cutting and wear-resistant category, then a reduction in welding and hardfacing consumption would have shown up as a reduction in cutting and wear-resistant consumption as well.

TOOL STEELS

Cobalt consumption in tool steels was definitely affected by the cobalt shortage. Users could shift from cobalt tool steels to existing tool steels that were cobalt-free; R & D efforts led to the development of additional tool steels that could replace the cobalt tool steels. The effects were more noticeable in Europe, where tool steels are a much larger percentage of total cobalt consumption.

CATALYSTS

The high cobalt prices in 1978 and 1979 had little immediate impact on cobalt consumption in catalysts. Research programs were started by both the producers and the consumers of the hydrodesulfurization catalysts, to replace cobalt-molybdenum catalysts with nickel-molybdenum ones. At the time these research programs were not expected to meet with great success. In other catalytic applications for cobalt, little could be done to reduce consumption or to find substitutes.

OTHER CHEMICALS

What happened to cobalt consumption in other chemicals during the shortage years is a matter of opinion more than anything else, because the change in reporting practices for these categories led to an abrupt break in the data series. The consumption of cobalt in feed additives reportedly was reduced significantly, the explanation being that cobalt feed additives had been oversold in the past and were simply not needed. If this explanation is correct, much of the feed additive market, which is actually quite small, has been lost permanently. The largest use included in these other chemicals is in driers for paints, inks, and so forth. The cobalt shortage certainly caused some substitution away from cobalt in driers, with consumers replacing some of the cobalt in a drier with manganese and/or zirconium. The cobalt shortage probably reduced consumption in driers by 10 to 30 percent. Cobalt consumption was probably reduced substantially in frits as well, with users switching partially to nickel and manganese.

RECYCLING

Recycling became very important to the cobalt market in 1978-1979, probably to an even greater extent than the available data indicate (refer to Table 2-7). Recycling programs began to play important roles in superalloys, carbides, catalysts, and some other uses.

SUPERALLOYS

With the high cobalt prices of 1978-1979, virtually everyone in the superalloy pipeline, from the superalloy producer to the fabricator to the gas turbine producer, started to recycle cobalt scrap. In the past most of this scrap had been mixed with other materials and sold to the steel industry as general alloy additives. The high-valued components of the scrap, such as

cobalt, were therefore lost. With cobalt prices high, everyone began to segregate scrap very carefully by alloy specification. Scrap segregated in this fashion could be sent back to the alloy melter to be used in producing the same alloy grades. The jet engine industry had generally operated under a rule of thumb that the buy:fly ratio for engine components was about 3 or 4, with most of the extra material being lost permanently in scrap. With these recycling programs, much less of the cobalt in the scrap was lost permanently to the production cycle. The buy:fly ratio remained unchanged if scrap was not accounted for, but if the recoverable cobalt in the scrap is subtracted from the new cobalt requirements, the effective buy:fly ratio was probably reduced to 2 or 3.

Of course, these recycling programs were not perfect. Turbine manufacturers in the past had normally specified that only virgin materials could be used in producing alloys for their products. After the recycling programs were instituted, they permitted scrap from known sources (e.g., their own operations and those of their fabricators) to be used as well. They still limited, however, the use of material from other sources. Some scrap still could not be recycled easily, due to unavoidable contamination in grinding operations and the like.

Attention was devoted to recycling old turbine parts as well. One method developed by a superalloy melter was to tear apart old gas turbines carefully, classifying each part by alloy type and segregating accordingly. These old parts could then be melted and refined in a standard furnace used by the superalloy melter, retaining the cobalt, nickel, chromium, and other heavy metals, but losing the reactive metals like aluminum and titanium. This method was developed in the later stages of the cobalt shortage, and was not used extensively.

Estimates of the total amount of cobalt saved by these various recycling programs is not readily available.

CATALYSTS

The cobalt shortage increased interest in recycling cobalt catalysts, particularly the cobalt-molybdenum catalysts, because molybdenum prices were also high at the time. Technical problems arose in the processing of the cobalt-molybdenum catalysts, however, and reprocessing operations that were instituted in this time period recovered molybdenum but not cobalt. Other reprocessing operations were more successful, however. Successful plants were constructed to recycle the cobalt catalysts used in the polyester industry. The petroleum industry began to clean its old catalysts if possible, burning off carbon if heavy metals had not poisoned them. This extended the active life of the hydrodesulfurization catalysts used in less severe conditions.

CUTTING AND WEAR-RESISTANT MATERIALS

The recycling of tungsten carbide cutting materials became increasingly important in the 1978-1979 period, but not really for reasons concerning the cobalt market. Technology had finally been developed to the point that recycling tungsten and mixed carbide cutting materials was economically feasible. In some processes the materials are segregated by alloy composition and converted back to mixed alloy powders, which can be mixed with virgin materials to produce new carbide tools. Hydrometallurgical methods can be used instead, recovering cobalt and other materials separately. The application of both methods became important in 1978-1979, and continues to grow. Most new carbide scrap is now recycled, and recycling of old scrap amounts to perhaps 30 to 50 percent of carbide consumption.

OTHER

Recycling in other applications was less important. Some cobalt residues, however, were melted by custom processors in small batches and returned to their source. For example, sulfur-rich residues generated in producing magnets could be cleaned of their sulfur and some other contaminants, and melted into a master alloy that could be used in producing similar magnetic alloys.

PRIVATE STOCKS AND GOVERNMENT ACTIVITY

Private stocks of cobalt in the United States fell as a percentage of consumption in 1978, but rose in 1979. This is not unexpected, since the surge in demand helped cause the shortage in 1978, and demand fell in 1979 while the supply problems began to ease. Consumer stocks of cobalt in the United States actually rose in 1978 in absolute terms, when consumers, worried about the continued availability of cobalt, bought all that they could find. To a large extent this simply shifted the ownership of the cobalt from the producers to the consumers.

Government interest in cobalt naturally increased in the midst of the cobalt shortage, particularly in response to repeated requests from industry that some of the cobalt in the strategic stockpile be released. Stockpile releases were not made, however, because they were not needed for defense or essential civilian purposes, and releases from the stockpile are limited by law to such uses. This does not apply, of course, to sales of excess materials in the stockpile, which in the case of cobalt stopped in 1976.

The U.S. government was active in other ways, however. The U.S. Department of Commerce instituted an export reporting system for cobalt in January 1979. This did not limit the exports of cobalt, but it did collect information on the amount of cobalt in different forms that was leaving the country. Exports for the most part were wastes and scrap.

The proposed River of No Return wilderness area in Idaho included part of the zone of cobalt mineralization being investigated by Noranda near the old Blackbird mine. In late 1979 legislation creating the wilderness area was approved, but this legislation called for cobalt mining to be considered one of the prime potential uses for the small section of the wilderness area in which cobalt was thought to exist. The same legislation restricted all mining activities to be underground, to minimize the environmental impacts on the area. This was expected to have no immediate impacts on Noranda's plans, because the mine being considered was underground.

The U.S. Bureau of Mines continued its research into ways to produce cobalt and to make better use of it. Research activities included processing routes based on material from West Coast laterites, the Duluth gabbro, Missouri lead ores, the Blackbird mine, and manganese nodules. Other research included developments in producing cobalt-rare earth magnets.

Foreign governments began to take a more active interest in cobalt. France, West Germany, Japan, and the United Kingdom all announced plans to investigate or to begin stockpiling of critical metals, including cobalt. This activity was spurred by the shortage of cobalt, molybdenum, and tantalum in 1978-1979. Little if any stockpiling of cobalt was actually carried out by foreign governments in this time period. The British government reportedly arranged to make loans to the mining companies in Zambia in return for guarantees that cobalt would be readily supplied to Rolls Royce and other large consumers of cobalt in the United Kingdom. Little information is available on this subject.

SUMMARY

With the surge in cobalt demand in 1978, the fears over continued availability of cobalt from Zaire, the low levels of producer stocks, and the limited potential for increasing production immediately, the cobalt market boomed in 1978 and, to a lesser extent, in 1979. An active dealer market for cobalt arose, to transfer cobalt from minor producers and from consumers with excess stocks to consumers who could not satisfy their needs from the major producers.

Supply did respond somewhat to the cobalt shortage, although not immediately. Capacity in Zambia increased from 1,800 metric tons before the shortage to 3,600 metric tons by the end of 1979, although this increase was not caused by the shortage. Further capacity increases in Zambia were planned, amounting to an additional 3,200 metric tons. These may have been motivated at least in part by the cobalt shortage. Cobalt recoveries in Zambia certainly responded to the high cobalt prices in 1978 and 1979. Overall recoveries of cobalt in Zambia had been in the range of 30 percent in 1978 and 1979, but by 1980 they had risen to about 40 percent.

The Canadian nickel companies responded in various ways to the cobalt shortage. Sherritt Gordon increased the annual cobalt capacity of its refinery from 500 metric tons to 600 metric tons by the end of 1979, with further increases planned. Falconbridge increased the cobalt capacity of its nickel refinery in Norway from about 1,000 metric tons annually to 1,800 metric tons by the end of 1979, although it only has enough refinery feed to produce about 1,300 metric tons at current nickel production levels. Inco announced vague but ambitious plans to double its cobalt production, from about 700-800 metric tons annually to about 1,500-1,600. It did not do so immediately, however, and its efforts to keep production at its former level were hampered by a nine month strike at its major nickel operations in Canada in 1978-1979.

Finland increased its cobalt capacity from about 1,000 metric tons before the shortage to about 1,450 metric tons by the end of 1979, but this increase had been planned earlier. Production in the Pacific region increased fairly substantially, partly due to the cobalt shortage and partly for other reasons. Greenvale (Australia) and Marinduque (Philippines) were nickel laterite projects that came into production in the mid-1970s, sending cobalt intermediates to Japan for refining. The mines and refineries increased production toward capacity in the several years after their opening, so their output rose steadily during the cobalt shortage. They did, however, take steps to increase cobalt production above the levels it would otherwise have reached. Greenvale selectively mined cobalt-rich parts of its orebody, and Marinduque increased the cobalt content of its intermediates.

Interest in cobalt production rose in other parts of the world, but production was not immediately affected anywhere else.

The effects of the high prices on cobalt demand were not felt immediately, but gradually and into 1980 and 1981. U.S. cobalt demand in superalloys eventually fell by about 10 percent as a result of the high prices, and demand in magnets fell by about 40 percent due to price effects. Most of these declines were probably permanent. Cobalt consumption in cutting and wear-resistant materials (cemented carbides) and in catalysts was not immediately affected by the cobalt shortage. Cobalt consumption in other uses probably fell by 10 to 30 percent as a result of the high prices, but these declines are reversible with lower cobalt prices. Probably only one-third to one-half of these price impacts were effective by the end of 1979.

Recycling became very important during the cobalt shortage, probably saving 10 to 25 percent of domestic consumption in superalloys, and lesser amounts in other metallic uses. Much of this recycling involved new scrap that might not be included in the available data.

4

COBALT IN THE 1980s

The cobalt market continued to weaken in 1980 and collapsed in 1981 and 1982. The increases in production caused by the cobalt shortage began to appear in 1979 and 1980. At the same time, the overall demand for cobalt began to fall, due to the weak economies in the United States, Europe, and Japan. U.S. cobalt consumption in 1981 was at its lowest level in over five years, but it fell even further in 1982. Demand has fallen similarly in Europe and Japan, partly due to their weak economies, and partly due to substitution and conservation measures.

As a result, the cobalt bubble burst in 1981. The producer price was lowered in several steps from $25.00 per pound at the beginning of the year to $17.26 per pound in September, with few sales being made at that price. The free market price plummeted from about $21.00 per pound at the beginning of the year to under $10.00 by December, after which it rebounded slightly. In early 1982, the producer price was cut again, to $12.50 per pound. The free market price drifted down to under $10.00 per pound. In mid-1982 Sozacom announced that it too would discount from its announced price, and began making sales at prices reported to be under $10.00 per pound. The free market responded, with the price sinking to about $6.00 per pound. Supply is likely to exceed demand for the next several years, which will maintain the downward pressure on prices.

One legacy of the cobalt shortage of 1978-1979 is a well-developed free market. Most highly concentrated markets with a producer price, such as aluminum, nickel, molybdenum, and copper (in the United States), have seen

strong free markets develop over the last decade. Whether such a free market would have developed in the cobalt market without the shortage of 1978-1979 will never be known, but it is clear that the cobalt merchant market will persist for some time to come. Producers outside Zaire will readily discount from whatever price Zaire is charging in order to sell all of their cobalt and to prevent their stocks from building up. They can sell this material directly to consumers, or, in the case of the smaller producers, through merchants. As long as cobalt capacity exceeds demand, and as long as they can cover their operating costs (however they might be defined, which is not a trivial question), they will continue to feed material to the free market.

SUPPLY

Cobalt expansion activities around the world slowed down in 1981 and came to an almost complete stop in 1982. The only activities now being seriously pursued are those already well under construction at the time of the price collapse.

ZAIRE

Cobalt production in Zaire remained high in 1980 and 1981, partly because the influx of cash from the high cobalt prices of 1978 and 1979 permitted Gecamines to purchase new mining trucks and parts, and to obtain additional supplies of fuel oil to permit stripping to be carried out. With the collapse of the market in 1981 and 1982, such spare cash was no longer to be had, and the financial and physical problems of 1975-1977 are likely to recur. Another invasion is unlikely, however, so adequate supplies of cobalt should be available from Zaire through the late 1980s.

The country's financial problems are possibly even more severe than those of Gecamines. Zaire has been forced to reschedule its foreign debts several times since 1979, and in 1981 Zaire failed to meet performance criteria that would permit it to make further drawings against an IMF loan. Zaire's debts to the rest of the world of about $4 billion are in serious jeopardy.

Zaire's potential for cobalt capacity expansion is enormous. The P2 expansion project of Gecamines, on indefinite hold at present, will add 6,000 metric tons to the current 16,800 metric-ton capacity. The Tenke-Fungurume project, a much more distant possibility for a government-foreign consortium, could eventually add another 4,500 metric tons to Zaire's capacity. Of more immediate concern to Zaire is maintaining copper production at its current nominal capacity, despite shortages of parts, supplies, and fuel.

ZAMBIA

In 1980 RCM announced several projects that would affect its cobalt production. RCM is eliminating bottlenecks in its refinery, in order to permit production at capacity. In addition, RCM is adding a vacuum induction furnace, so that it can vacuum refine some of its cobalt, to improve its quality. The Chambishi refinery uses lead-antimony anodes, so the refined cobalt has a lead content that is unacceptably high for superalloy applications. Improving the quality of RCM's cobalt will improve its saleability in a weak market.

NCCM is at present concentrating on completing its new roast-leach-electrowin plant, and on improving operations in its old refinery.

With the merger of the two companies in 1982, increased cooperation between them, particularly in matters concerning cobalt recovery, is quite likely.

FINLAND

Outokumpu Oy, in an attempt to expand its sales potential, began to produce a variety of cobalt chemicals and to market them directly to consumers in the United States in 1982. Given the rate of depletion of its ores, Outokumpu Oy is likely to need new sources of cobalt for its refinery by the end of the 1980s.

CANADA

In early 1980 Inco announced plans to build a new electrolytic cobalt refinery at its Port Colborne, Ontario, operations, near Niagara Falls. This refinery is scheduled to be completed in late 1982, with a capacity of 900 metric tons annually. It is likely to process some of the material currently being toll-refined by Falconbridge and Sherritt Gordon, and some of the cobalt currently going into oxide and salts. Improved cobalt recoveries in Canada will permit Inco to increase its overall cobalt production. Unfortunately for Inco, the continued weakness in the nickel market forced it to shut down its Guatemala operation in 1980 and to mothball it indefinitely in 1981. This would not have been a major source of cobalt for Clydach, but its loss will reduce Inco's cobalt capabilities somewhat. Similarly, Inco has been forced to delay the expansion of its Indonesia operation, which would have supplied additional nickel matte to Clydach. Without matte from its Indonesia and Guatemala operations, Inco may be forced to reduce the amount of material being tolled by Sherritt Gordon and Falconbridge more than it had originally planned. The most recently available information is that Inco will halt the production of cobalt salts, and its oxide production will be well below its oxide capacity. The electrolytic refinery will operate at capacity, however.

Although the nominal capacity of Falconbridge's cobalt refinery is 1,800 metric tons annually, Falconbridge has only had enough refinery feed to produce about 1,300 metric tons in recent years. When Inco opens its new electrolytic cobalt refinery, some of the residues going to Falconbridge may no longer be available. Falconbridge is unlikely to be able to operate its cobalt refinery at capacity until the nickel market recovers sufficiently for it to increase mine production in Canada. In 1982 and 1983 Falconbridge will treat some nickel-copper matte from the sulfide project in Botswana.

Sherritt Gordon increased its cobalt capacity from 600 metric tons annually at the end to 1979 to about 1,000 metric tons by the end of 1981. If it had adequate feed materials, Sherritt Gordon could easily expand capacity by another 50 percent or so. Such feed is unlikely to be forthcoming. The residues from Inco and the mixed sulfides from Impala Platinum will no longer be available when these companies open their new cobalt refineries in late 1982 and 1983, so Sherritt Gordon may not have enough feed in the next few years to operate its cobalt refinery at capacity.

As of the beginning of 1983, the effective cobalt capacity of the Canadian nickel companies will total about 3,500 to 4,000 metric tons annually.

PACIFIC

The Pacific region is unlikely to see any new cobalt projects in the 1980s. With the collapse in cobalt prices, both Marinduque and Sumitomo found the terms of their new agreement onerous. Sumitomo is committed to purchase mixed sulfides from Marinduque on the basis of the producer prices for both nickel and cobalt. When the free market prices for cobalt and nickel are both well below the producer price, Sumitomo finds itself squeezed between its purchase price and the sales price it can realize. Marinduque began to complain about the clause in the contract that obliged it to purchase back some of the cobalt at producer prices, which it sells at free market prices.

Both Marinduque and Greenvale have instituted programs to substitute coal for oil in drying ore and operating boilers. This should reduce production costs considerably. Nonetheless, Marinduque and Greenvale are still relatively high-cost nickel producers, especially Marinduque, and both could shut down if nickel prices remain low or weaken further.

FRANCE

Speciaux Metaux announced in 1982 that it may be forced to cease production in 1983 due to the low levels of cobalt concentrate production in Morocco. The refinery would not have a suitable feedstock, should the Moroccan mine and concentrator shut down.

SOUTH AFRICA

In 1981, MRR completed construction of its new nickel-copper-cobalt refinery. Between the cobalt circuit on this refinery and the cobalt circuit added to its old refinery in 1979, MRR will now recover cobalt from all of its nickel-copper matte, giving it a total cobalt capacity of about 500 metric tons annually, contained in the form of sulfate. As noted above, Impala Platinum plans to open a new cobalt refinery in 1983. Other cobalt projects under consideration in South Africa, such as the gold slimes operations, have been placed on hold, probably permanently.

Future expansions of the platinum industry in South Africa will not necessarily imply increases in cobalt production. All platinum recovery in recent decades has been from the Merensky Reef, the major platinum zone in South Africa. Future production will come from the UG2 reef as well, and this orebody contains very little cobalt. Rustenburg Platinum and Impala Platinum own considerable reserves in the Merensky Reef that are as yet undeveloped, so they may not be interested in developing the UG2. Western Platinum, a minor producer, and other companies without good access to Merensky Reef reserves are more interested in UG2.

UNITED STATES

The Amax refinery treats nickel-copper matte from many sources, as discussed above. Current sources of matte include Botswana and the Agnew project in Australia. Amax has very high stocks of untreated nickel matte on hand, so it has renegotiated its contract with Botswana. In 1982 and 1983, some of the matte from Botswana will be diverted to other refineries, including Falconbridge in Norway and RTZ in Zimbabwe. In 1981, in an attempt to increase the sales potential for its cobalt, AMAX began to market what it called sintered cubes. Heating the powder drives off some of its impurities, and forming it into solids makes it easier for the alloying industries to handle it. The resulting product may or may not be adequate for the most stringent applications, but it is certainly improved by the sintering. Plans to renovate the operations in the refinery and to treat cobalt residues from AMAX's lead-zinc operation in Missouri have been placed on hold.

Most other projects considered during the height of the cobalt shortage have been abandoned. Both Anschutz and Noranda performed a considerable amount of on-site and laboratory work in 1980 and 1981, in evaluating their cobalt properties. Both eventually came to the same conclusion: cobalt could not be profitably produced at a price of less than $20 per pound (1980 dollars), so both companies requested some form of government support under Title III of the Defense Production Act. When such assistance was not forthcoming, both companies essentially shut down their cobalt investigations, after spending tens of millions of dollars.

In 1980 California Nickel announced that it was investigating a low-grade nickel-cobalt laterite deposit near Gasquet Mountain, California. The ore averages 0.75 percent nickel and 0.071 percent cobalt, plus about 2.0 percent chromium. The planned annual capacities are 1,170 m.t. of cobalt, 12,400 m.t. of nickel, and 18,000 m.t. of chromium contained in 42 percent Cr_2O_3 concentrates. A $250 million complex is planned. An acid leach process is envisioned, to realize high cobalt yields. California Nickel claims that its capital costs will be relatively low because the infrastructure is in place, power and port facilities are available, and the deposit is reasonably accessible. This project would appear to be a high-cost nickel operation, with cobalt as a byproduct. Chromium revenues for the project would be only a few percent of nickel plus cobalt revenues. The project seems unlikely to succeed without a subsidy of some kind.

OTHER

No new sources of cobalt are likely to be important in the 1980s. Both Falconbridge and Sherritt Gordon have explored the feasibility of processing the cobalt-rich pyrites in Uganda, and both have given up on the project. According to company officials, the Ugandan government wants the old copper mine and smelter to be rehabilitated, but the reserves at the mine do not warrant the expense of doing so. The pyrites alone may be worth treating if cobalt prices are sufficiently high, but not when the cobalt price is only $6 per pound.

Possible nickel-laterite projects in New Caledonia, Burundi, and Papua New Guinea could increase world supplies of cobalt, but probably not in the 1980s. The world nickel market is suffering an even worse case of overcapacity than are the cobalt and copper markets. Ambitious expansion plans in the early 1970s, coupled with negligible growth and rapidly escalating energy costs, have led to a situation in which the long-run cost of producing nickel is more than double the current free market nickel price, production is averaging less than 60 percent of capacity on an industry basis, and demand is expected to grow little faster than industrial production in the coming decade. Under these circumstances, current nickel capacity, active and mothballed, should be adequate to supply the nickel market well into the 1990s. As a result, little new cobalt is expected to come from nickel operations in this decade. As the nickel market recovers and producers like Inco and Falconbridge increase their production of nickel, some additional quantities of cobalt will come onto the market. Existing and near-term cobalt capacity should be adequate to handle these materials, however. The potential for increasing cobalt production further from existing nickel operations is limited.

By the mid-1990s cobalt may be recovered from deep-sea manganese nodules, or from manganese crusts on seamounts. A single manganese nodule operation might produce 1,500 to 4,500 metric tons of cobalt annually, depending on the scale of the operation and on the cobalt recoveries achieved.

Some of the substitution and conservation activities instituted as a result of the cobalt shortage in 1978-1979 are likely to be reversed with the fall of cobalt prices back to (and temporarily below) more normal levels. Others are not.

SUPERALLOYS

The oil price increases of 1978-1979 and the ensuing recession in the noncommunist world punctured the aerospace boom. The air traffic controllers strike in the United States in 1981 played a role also, but probably a lesser one, in reducing the demand for new aircraft. U.S. demand for cobalt in superalloys increased in 1980, the only major sector to do so, and when it collapsed in 1981 so did the entire U.S. cobalt market. By the end of 1981, most of the short-run substitutions that could be implemented without major development programs had been put into effect. These substitutions are unlikely to be reversed, at least for several years. Some R&D programs to reduce cobalt consumption had been instituted during the cobalt shortage, and work on them is expected to continue, at least temporarily. Little information is available on these private R&D programs.

No major new substitution programs are being contemplated, however. Work is continuing in a number of research areas, including single crystal alloys, rapid solidification, and hot isostatic pressing. As discussed previously, this research was not really motivated by the high cobalt prices, so it continued when cobalt prices fell.

MAGNETS

Most of the substitution programs stimulated by the high cobalt prices of 1978-1979 have now been completed. Without another runup in prices, further substitution is unlikely. Magnets, particularly loudspeaker magnets, are an area in which the substitution activities undertaken in 1978-1979 are to a great extent irreversible. This issue has already been discussed. In some other areas, such as automobile speedometers, where tradeoffs were made between the reduced performance of the ferrites and the high price of cobalt, substitutions are more likely to be reversed. Very few such substitutions were actually made, however.

Cobalt-rare earth magnets still have an excellent potential for growth in totally new areas for cobalt-containing magnets, particularly if would-be consumers are convinced that cobalt supplies and prices are likely to be relatively stable in the years ahead. One of the most promising areas is in light-weight electric motors. Using cobalt-rare earth magnets can reduce the weight of a motor by one-third to one-half. A recent example of an application of cobalt-rare earth magnets is in the Sony Walkman, which contains these magnets both in the headphone speakers and in the drive motor for the tape player. This does not in itself constitute a major use for the

cobalt-rare earth magnets, but it indicates the kinds of applications for them that can develop. In general, ferrites will be used in applications that are not limited by size, weight, or temperature stability. Alnicos will probably be used in applications that require temperature stability, but are not limited by size or weight. The cobalt-rare earth magnets will be used in the more specialized applications.

CUTTING AND WEAR-RESISTANT MATERIALS

Events in the cobalt market have had very little impact, nor are they likely to in the future, on cobalt consumption in this use. The few R&D programs that were instituted met with little success, but they were not expected to. Any substitutions of nickel for cobalt in binders are likely to be reversed with cobalt prices at or near historical levels.

WELDING AND HARDFACING MATERIALS

Acceptable substitutes were found for cobalt in many hardfacing applications as a result of the cobalt shortage, but most of the substitutions that have been made are probably reversible at more usual cobalt prices. In some specific applications, such as those in the steel industry requiring abrasive wear and corrosion resistance at temperatures above 1200° F, cobalt is still thought to be necessary.

TOOL STEELS

Some of the substitutes for cobalt high-speed steels developed during the height of the cobalt shortage did not find widespread acceptance at the time because they required considerable amounts of molybdenum, which was also in short supply at the time. These steels are likely to find their own niche in the market, now that both cobalt and molybdenum prices have collapsed. Whether they will take a larger part of the cobalt high-speed steel market is not yet clear. What is clear is that they would take a very large part of the tool steel market should cobalt prices increase in the future as they did in 1978-1979.

CATALYSTS

The research programs instituted to develop nickel-molybdenum catalysts to replace cobalt-molybdenum catalysts in hydrodesulfurization operations met with unexpected success. As a result, even with the recent decline in cobalt prices, the use of nickel-molybdenum catalysts is likely to continue to grow in the future, at the expense of the cobalt-molybdenum catalysts. Overall consumption of cobalt in these uses may or may not actually drop, but its growth will certainly be slowed. The direct impacts of these developments are difficult to quantify, because not all catalytic reactors can use these new catalysts.

Interest in recycling these hydrodesulfurization catalysts remains high, and two new reprocessing plants are scheduled to open in 1983. This would limit the demand for cobalt in hydrodesulfurization catalysts to the amounts needed to load new catalytic reactors, plus the amounts lost in reprocessing. Hydrodesulfurization catalysts currently consume roughly 1 million pounds of cobalt annually in the United States. With widespread recycling, this could be cut by 75 to 90 percent.

The demand for cobalt catalysts could possibly expand severalfold in the next 20 years, if coal liquefaction and gasification plants become common and if the processes in these plants use cobalt catalysts. This statement contains two large qualifications, and omits a third. First, it is by no means clear that such synthetic fuels plants will be commercially viable in this century, let alone this decade. Second, given current technology these plants are just as likely to use nickel catalysts as cobalt catalysts, if not more so. And third, the catalysts used in such plants are likely to be reprocessed.

DEPENDENCE ON ECONOMIC ACTIVITY

The demand for cobalt in superalloys will remain slack until the aerospace market recovers, which is likely to be two or more years away, but could prove to be strong. Cobalt consumption in magnets has a potentially bright future in as-yet undeveloped uses, as discursed above. The demand for cobalt in cemented carbides will depend to some extent on the strength of the oil market -- high oil prices mean substantial drilling activity and strong demand for drill bits. In all other uses, cobalt demand is likely to grow at about the same rate as industrial production.

OTHER ISSUES

Other issues include recycling, stocks, and government activities. All affected the cobalt market from 1980 to 1981, but their influence in the future may be somewhat reduced.

RECYCLING

The major recycling programs instituted in 1978 and 1979 were continued into 1982, but it is not clear how much longer they will continue, except for the cutting and wear-resistant materials. Segregating alloy scrap by composition consumes labor and storage space, neither of which is a free good. With the downturn in cobalt prices in 1981 and 1982, the economic benefits of recycling are greatly reduced, possibly to the vanishing point. It is still too early to see how long the recycling programs can last with the prices for cobalt, molybdenum, tantalum, and nickel depressed. The recycling of

cemented carbides is an entirely different issue because, as noted previously, it depends on the economics of tungsten much more than on the economics of cobalt.

PRIVATE STOCKS

Cobalt production in the noncommunist world exceeded demand by a sizeable margin from 1980 to 1982, and with two major new refineries coming into production between 1982 and 1983, the gap is likely to linger for some years. This will continue to put downward pressure on prices. High interest rates in the United States, and hence in the rest of the world, have contributed to the reluctance of consumers to build stocks back up to more normal levels. Probably of greater importance, however, has been the reluctance of consumers to purchase additional material when demand is weak and prices seem likely to decline even further.

GOVERNMENT ACTIVITIES

Government activities were important again in the 1980-1982 period, although they seem less likely to be important in the future. The most important single action by the U.S. government was the purchase in 1981-1982 of 5.2 million pounds of cobalt for the stockpile. The original solicitations for stockpile material were circulated in the second quarter of 1981. In July 1981, the GSA announced that it would purchase 5.2 million pounds of cobalt from Zaire, taking delivery over the course of the next 12 to 18 months. The purchase price was fixed at $15 per pound. This announcement took the cobalt market by surprise, because the official producer price at the time was $20 per pound, and the free market price was about $17 per pound. The stockpile announcement was the occasion for the eventual collapse of the cobalt free market price in 1981 to the $10 per pound level. It did not cause the collapse, but it did reveal the softness in the market.

Many government agencies were busy studying cobalt in the 1980-1982 period. Studies were commissioned or performed by the Department of the Interior, the Bureau of Mines, the Department of Commerce, FEMA, the Congressional Budget Office, and the National Materials Advisory Board (on behalf of the Bureau of Mines). In addition, NASA instituted its COSAM program, which involves looking into the conservation of metals like cobalt in aerospace applications. The Bureau of Mines, of course, continued with research into the use of domestic ores in producing cobalt. These studies all served to heighten interest in cobalt and direct attention to minerals issues in general, but it is not clear what collective impact, if any, they have had or will have on the cobalt market.

The U.S. government could have had a major impact on the cobalt market in one other area but declined to do so. The government decided not to provide financial support through Title III of the Defense Production Act to any of the companies seeking it.

Plans for stockpiling by other governments essentially collapsed between 1980 and 1982. The French government in fact proceeded with the stockpiling of a few hundred metric tons of cobalt, considerably less than 20,000 metric tons already in the U.S. stockpile. The West German government cancelled its stockpiling program in an economy move just before it was to be implemented. The Japanese government decided to go ahead with stockpiling, but on an even smaller scale than the French, and they have yet to do so. Stockpiling never got beyond the study stage in Great Britain.

SUMMARY

The long-run impacts of the cobalt shortage of 1978-1979 are as yet difficult to quantify. Something less than 3,000 metric tons of capacity increases can be directly attributed to the cobalt shortage, although the new NCCM refinery in Zambia might be attributed in part to the shortage. Substitution programs in the United States have led to long-run declines in demand of about 10 percent in superalloys, 40 percent in magnets, and 10 to 25 percent in catalysts. Recycling programs, which were instituted very successfully during the shortage, may not be able to survive the low prices that followed. Some recycling operations, notably the plants to recover molybdenum, cobalt, nickel, and vanadium from the hydrodesulfurization catalysts, have yet to open. In the long run, growth in the demand for cobalt will depend on: the aerospace industry for superalloys; new uses for cobalt-rare earth magnets; and industrial production for other uses.